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GEOLOGY AND ORE DEPOSITS OF THE BRECKENRIDGE MINING DISTRICT, COLORADO

BY

T. S. LOVERING

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ABSTRACT OF REPORT

A small portion of the Breckenridge mining district, originally mapped by Ransome, was remapped by the writer on a larger scale. In addition to the geologic data supplied by deeper mining since the earlier report was written, information gained in a study of the surrounding region has helped interpret the stratigraphy and complicated structure of the district itself.

Pre-Cambrian schist, granite, and granite gneiss underlie the sedimentary rocks of the district and come to the surface in the northern and southern parts of the area mapped. The lower Paleozoic beds are not present. The Maroon formation (of Permian and Pennsylvanian? age) lies directly upon the pre-Cambrian rocks in the Breckenridge district. It is missing a short distance farther east, where it is overlapped by the Morrison and Dakota formations, but it thickens greatly to the south and southwest. The underlying Weber (?), if present, occurs only under a thick cover in the southern part of the district. The Maroon formation consists of 600 to 900 feet of red, gray, and black micaceous sandy shale with some limestones and some red and gray micaceous grit and conglomerate. The Maroon is overlain by about 200 feet of sandstone and variegated shale belonging to the Morrison formation, of Upper Jurassic age.

The Upper Cretaceous Dakota quartzite, which rests upon the Morrison formation, ranges from 125 to 165 feet in thickness in the special area mapped by the writer. In the surrounding region it ranges from 20 to 225 feet. Probably because of its rigidity and its ability to contain open fractures, ore bodies are commonly localized in the quartzite where veins pass through it.

The dark Benton shale overlies the Dakota quartzite and is about 360 feet thick. At the top of the Benton is a bed of shaly limestone about 25 feet thick, which is probably the equivalent of the †Nio-Benton sand[1] of North Park. The Niobrara formation is about 350 feet thick and consists of black or gray limy shale interbedded with thin-bedded dark limestone.

Overlying the Niobrara formation is the Pierre shale, which has a thickness of about 4,000 feet near Keystone, 10 miles north of Breckenridge, but only the lower 500 feet is present in the special area. It consists chiefly of dark olive-colored and dark-brown clay shale.

Quaternary glacial and stream deposits rest upon the uneven surface of the older rocks in the Breckenridge district. The outwash from early Pleistocene glaciers forms high-terrace gravel. Moraines and outwash of the late glacial (Wisconsin) stage are also present. Valuable gold placer deposits have been found in the early glacial and late glacial outwash gravel and in the late glacial ground moraine.

Intrusive monzonitic porphyry of early Eocene age is common in the Breckenridge district. Most of the porphyry is a true monzonite in composition, but both diorite porphyry and quartz monzonite porphyry are also present. The monzonite porphyry generally occurs as sills, some of which are very thick, and only in a few places does it break across the sediments. It is cut by dikes and stocks of coarsely porphyritic quartz monzonite. A porphyry intermediate in composition and appearance as well as in age between the typical coarse-grained quartz monzonite porphyry and the monzonite porphyry occurs in sills, dikes, and small stocklike masses. In the remapped area a small stock near French Gulch has caused contact metamorphism in the limy shale of the Morrison formation nearby, and similar contact metamorphism has taken place elsewhere in the district.

The hydrothermal alteration of the wall rocks of the veins was thoroughly studied by Ransome, and little has been added to his conclusions. The solutions were of reducing character in most places, and the bright red sediments of the Maroon formation are changed to green or gray in contact-metamorphic zones and near ore channels. Where alteration was intense, silicification occurred on a large scale, and much of the dark Cretaceous shale near the Wellington mine has been completely converted into jaspery silica, similar to the flint or jasperoid of the Leadville district. Near the veins the porphyritic rocks have in places been completely altered to sericite, quartz, and ankerite with minor amounts of pyrite. A more widespread type of alteration is that in which the ferromagnesian minerals of the porphyry are changed to calcite and epidote and the feldspars are incompletely converted to calcite, sericite, and kaolinite.

The sediments of the Breckenridge district lie in an asymmetric syncline in which the general dip is toward the east. At the edge of this trough, 5 miles east of Breckenridge, the sediments are limited by an overturned fold that passes northward, through an east-northeast shear zone, into the large Williams Range thrust fault. At Keystone, 10 miles north of Breckenridge, this thrust fault has a known horizontal displacement of 4 miles. The trough of the syncline has been the site of much intrusive activity from South Park to the region a few miles south of Keystone. Much of the igneous rock occurs in large sills of diorite and monzonite porphyry, but stocks of quartz monzonite porphyry are also present.

The remapped area of the Breckenridge district is on the western limb of the regional syncline about 2 miles west of its axis. In the southwestern part of this area the prevailing northeasterly dip is broken by an open anticline and a compressed syncline, both of which trend northwest. Two broken down-faulted belts cross these folds and intersect near the central part of the area. One of these belts trends north-northeast and the other east-northeast. Both normal and reverse faults are common. The most productive mines of the district, the Wellington, Washington, Golddust, Dunkin, and Puzzle-Ouray, are situated in the east-northeast down-faulted belt. The veins in these mines follow premineral faults of small throw. Nearly all the productive veins strike between N. 40° E. and N. 80° E., and the fissures that they follow are generally older than the faults that strike N. 10° W. to N. 20° E. The bulk of the porphyry of the district was intruded after folding was completed, and part of it is later than the initial east-northeast faults, which were later mineralized. The large thrust fault at the east side of the district is earlier than the coarsely porphyritic quartz monzonite, but much of the faulting is later than the latest porphyry masses.

A study of the regional geology shows that the Breckenridge district lies in a northeastward-trending zone of weakness which first localized the intrusive activity and, slightly later, the mineralization of the region. This zone is known as the por-

[1] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U.S. Geological Survey.

phyry belt or the mineral belt and extends northeast across the Front Range to Boulder, Colo. This structurally incompetent belt comes to the western edge of the Front Range, where the Williams Range thrust fault breaks from the overturned fold. In the Breckenridge district the mineral belt is approximately 6 miles wide, and the complex fault mosaic represents largely the response of interbedded incompetent rocks to an east-northeast compression localized along a 6-mile front. The ores are largely confined to open premineral faults, but many of the veins are related to channels of mineralization that trend more nearly north than the veins. This relation is well illustrated by the occurrence of ore in the Wellington mine.

A wide variety of ore and gangue minerals has been found in the Breckenridge district, but the only ore minerals sufficiently abundant to be of commercial importance are gold, silver, sphalerite, galena, and pyrite. The primary mineralization is believed to be related to the solidification of the deeper parts of the quartz monzonite porphyry and is later than any of the porphyry intrusions. Enrichment has greatly modified many of the deposits. Contact-metamorphic ores, stockworks, veins, blanket ores, and placers occur.

Contact-metamorphic deposits have little economic significance in the Breckenridge district, but dense, irregular masses of silicates, intergrown with metallic oxides and sulphides, occur in several places and are best developed in the limy beds of the Niobrara and Morrison formations. These deposits are resistant to weathering and show little enrichment. Some of them contain appreciable amounts of gold and copper, but the ore bodies are usually small, spotty, and irregular in plan. They cluster around the stock of quartz monzonite porphyry to which ore deposition is closely related.

Stockworks are found chiefly in the northeast quarter of the Breckenridge district in a large mass of quartz monzonite porphyry outside of the remapped area. They are probably mineralized shattered zones formed in response to residual stresses in the shear zone between the major thrust fault and the overturned fold to the south. The country rock of the stockworks has been fissured in many directions, but the strongest and most persistent fractures are those that strike east to northeast. The primary ores are generally low-grade pyritic gold ores, containing small amounts of galena and sphalerite. Most of the ore occurs in small open fissures, and there has been little replacement of the country rock. Enrichment has been a notable factor in the upper part of the stockworks.

Most of the productive veins lie in a short, narrow east-northeastward-trending belt that extends from Little Mountain to Mineral Hill. With the exception of the rich narrow gold veins of Farncomb Hill, very few veins outside this belt have contributed materially to the output of the camp. Most of the veins occupy normal faults striking N. 40°–80° E. and dipping 60°–80° SE. or NW. They show pronounced irregularities in both strike and dip.

All the bedrock formations in the district are cut by veins, but most of the ore has been found where the vein walls are monzonite porphyry or Dakota quartzite. Minor quantities have also been produced from veins in each of the other formations except the Morrison, which has yielded little or none. The influence of the wall rock is largely physical. Faults passing through porphyry, quartzite, and silicified shale commonly have open fault breccias but on passing into unaltered shaly formations are marked by soft impervious clay-filled fissures. The chemical character of the wall rock has been less influential than its physical properties in determining the presence of ore, but certain limy layers in the Cretaceous beds are replaced by ore next to some of the larger veins. The ore shoots were localized in the more open parts of faults of moderate movement.

In the remapped area the primary ores consist largely of lead, zinc, and iron sulphides with some native gold and some silver whose form is uncertain. Ankerite, calcite, quartz, and sericite are the common gangue minerals. Some of the veins consist chiefly of pyrite and sphalerite and contain very little lead.

The bulk of the ore produced from these veins is pyritic zinc blende, which typically changes abruptly downward into nearly pure pyrite. More abundant than the ore of this class are the primary zinc-lead ores, which have a much larger proportion of galena throughout the vein and which commonly pass upward rather abruptly into a zone of sphalerite-free galena near the surface. The sulphides are generally massive and show no evidence of depositional banding or crustification.

Ore shoots made up chiefly of the more readily removed minerals, pyrite or sphalerite, show a negative relation to topography and occur below the zone of Tertiary oxidation. Gold ore and high-grade galena ores, however, appear limited to a zone that ranges from 200 to 300 feet in depth, corresponding roughly to the present topography. The mixed zinc-lead ores have a much greater range than the high-grade lead ores, and in the Wellington mine they have a vertical range of more than 800 feet. Practically no high-grade zinc ores have been found in the upper parts of veins that come to the surface in areas where preglacial topography is well preserved. The largest zinc shoots have all been found several hundred feet below the level of the Tertiary erosion surface, and their position probably reflects the ready removal of zinc sulphide from the zone above the Tertiary ground-water level.

A study of the topographic, mineralogic, and textural relations of the ores indicates that the presence of high-grade lead ore shoots near the surface is due to the leaching of the more soluble sphalerite and pyrite from a primary lead-zinc ore and that there has been little or no secondary deposition of the galena itself. The enrichment of the gold ores is easily demonstrated, and it is unquestionably concentrated by the agency of surface waters moving down toward the water table.

The mineral deposits that follow bedding planes, locally known as "contacts", are practically confined to Gibson Hill, Shock Hill, and Little Mountain and occur in replaceable beds of the Dakota quartzite and Maroon formation. Both primary and secondary ores of this type have been mined, but the most valuable concentrations have been apparently caused by the action of surface water. The most favorable situation for these replacement deposits seems to have been at the upper termination of minor veins.

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By T. S. Lovering

INTRODUCTION

SCOPE OF THE REPORT

In 1909 the Breckenridge district was studied by F. L. Ransome, assisted by E. S. Bastin. The results of this work appear in Professional Paper 75 of the United States Geological Survey. Ransome concluded that most of the essentially lead ore was confined to shallow depths, and, as the metallurgy of mixed lead-zinc ores had not at that time been satisfactorily solved, he was not optimistic over the future of the district. At the time of his study there were no accessible underground workings that were more than 400 feet below the surface.

The structure of the district is very complex, and much of the geology is hidden beneath a deep mantle of slope wash on the hills and a thick cover of alluvium in the broad valleys of the Blue River, French Creek, and the branches of the Swan River. It is obvious that a geologic map of 45 square miles in such a region, completed in 3 months of field work, must be more or less generalized. The extensive development of the Wellington mine, the additional work in the Detroit, Golddust, and Puzzle mines, and the large amount of dredging that has taken place since 1909 have supplied many significant geologic facts not available at the time the earlier report was written. The present study records new data and reviews the geology in the light of these new data as well as additional information gained in the surrounding region. A small portion of the district, which is the subject of this paper, was remapped on a scale of 1,000 feet to the inch, but only the geology of the bedrock surface, which lies from 1 to 80 feet below the actual surface, is shown on plate 2. In constructing the map the writer used underground data wherever they were available and then plotted the bedrock geology from the facts revealed by subsurface work. Little reliance can be placed on the materials found in the hillside wash as indicators of underlying bedrock, and only the large number of prospect holes sunk through the wash enable one to map the geology in much of the special area studied. The extensive dredging on French Creek has exposed bedrock fragments on most of the tailing piles. With a little study the weathered, angular fragments of bedrock can readily be recognized, and with allowance for the length and swing of the dredge a very satisfactory map of the underlying formations can be made. Such work outlined the quartz monzonite stock half a mile east of Breckenridge that is believed to be intimately related to the source of the adjacent ore deposits and was of great value in correlating the geology and structure on the north and south sides of French Gulch.

The stratigraphy has been revised, and the new subdivisions of the formations, shown on the special map, make it possible to give a more detailed picture of the structure than was possible on Ransome's smaller-scale map. The following are the outstanding changes: The †Wyoming formation is correlated with the Maroon formation of the areas to the west; the Morrison formation is separated from the upper part of the †Wyoming and the lower part of the Dakota as previously mapped in this region; the true Dakota (here chiefly quartzite) was studied in detail, its variations in thickness are considered with respect to its general distribution, and its overlap of the older formations is noted; the Upper Cretaceous shale of Ransome's report is subdivided into the Benton shale, the Niobrara formation, and the Pierre shale; and detailed sections of all the formations except the Maroon are given.

The detailed structure of the small special area is discussed and its relation to the regional structure is brought out. The problem of the enrichment of lead is considered, and experimental work on the solution and precipitation of lead compounds is presented; as a result it is concluded that moderate amounts of lead have been dissolved and reprecipitated in the form of cerusite but that very little supergene galena has been formed. Mine maps and stope maps of most of the mines in the special area are shown, and their geology is discussed briefly. The study of the Wellington mine, the largest producer in the Breckenridge district, is given in more detail, as the occurrence of ore in this mine suggests many factors that bear on the localization of ore shoots, and the conclusions reached find wide application in the district.

FIELD WORK AND ACKNOWLEDGMENTS

The surface geology of the special area of the Breckenridge district was mapped by the writer in the interval from May 27 to June 28, 1928, and the underground geology of the mines was studied at different times during 1927 and 1928, probably consuming about five additional weeks. Mr. L. B. Graff and Mr. H. W. Putnam, as field assistants, contributed materially to the speed of the surface work. It is impossible to name everyone to whom the writer should make acknowledgments for help and information on the district, but special mention should be made of the assistance and courtesies extended by Mr. R. M. Henderson, Mr. H. L. Tedrow, Mr. George Robinson, Mr. Neucombe, and Mr. John Nelson. The writer was freely admitted to all the mines in the Breckenridge district that were open at the time of his visit except the Royal Tiger.

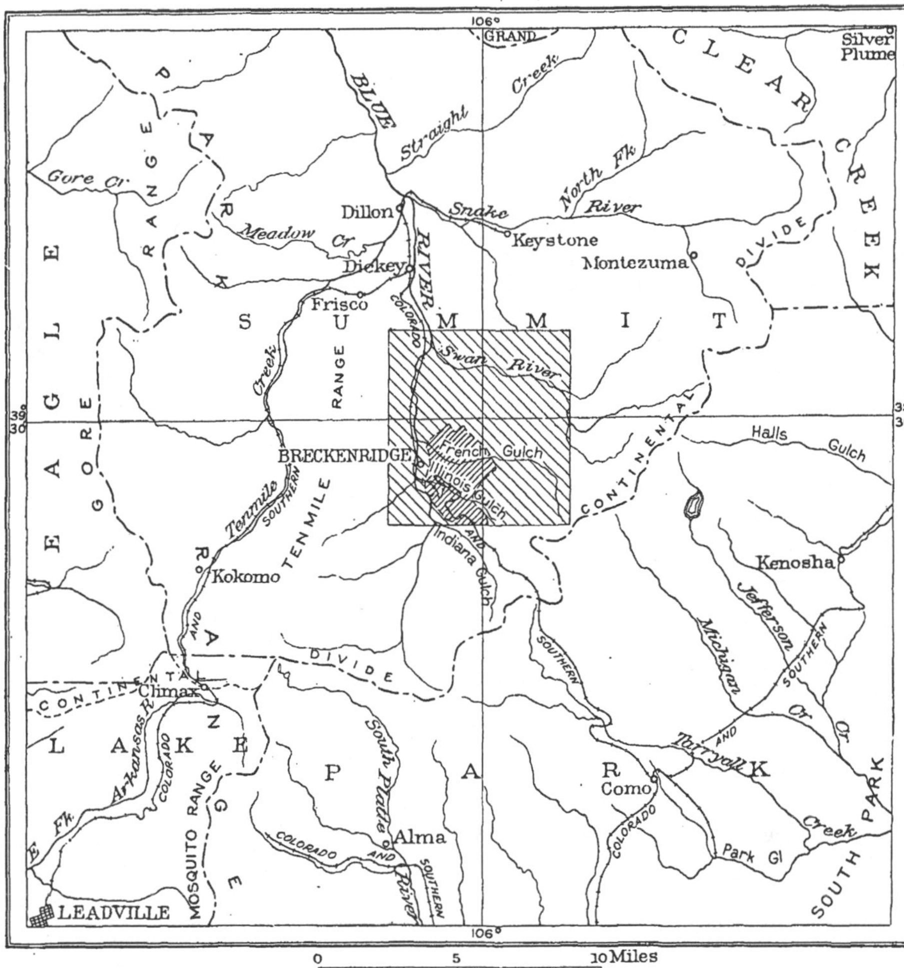


FIGURE 1.—Index map of Breckenridge district showing area restudied for this report (dark shading).

LOCATION AND TOPOGRAPHY

The Breckenridge district is only a few miles northwest of the geographic center of Colorado and lies on the headwaters of the Blue River, a tributary of the Colorado River. Its relation to nearby cities and towns is shown in figure 1; it is about 60 miles west of Denver and 20 miles northeast of Leadville. The district mapped by Ransome lies between latitude 39°27′ and 39°33′ and longitude 105°57′ and 106°4′ and covers 45 square miles. The small part of this region restudied by the writer is near Breckenridge, where most of the chief productive mines of the district are situated. In this report it is distinguished as the special area; its relation to the larger district mapped by Ransome is shown in figure 1.

The district mapped by Ransome ranges in altitude from 9,100 to 13,100 feet, and to the east, west, and south the mountains attain even greater heights. In general the district is decidedly hilly, although little of it would be described as rugged. The area covered by this supplementary report includes only a few hills, of minor prominence. The lowest point is on the Blue River at an altitude of 9,500 feet, and the highest is near the top of the hill a mile east of Bacon, at 11,500 feet, a difference in altitude of 2,000 feet.

French Gulch follows a westerly course across the northern part of the special area and separates Gibson

Hill and Prospect Hill on the north from Nigger Hill and the northwestern spur of Bald Mountain on the south. (See pl. 4, *B*.) South of this spur and Nigger Hill the special area is crossed in a northwest course by Illinois Gulch. Little Mountain and the unnamed ridge southeast of Rocky Point lie between Illinois Gulch and the Blue River. The relation of these streams to one another is shown in figure 1, and the details of the topography can best be seen on plate 1.

HISTORY OF MINING

Ransome[3] gave a summary of the history of the Breckenridge district from 1859 to 1909, and Henderson[4] has recently given a detailed account of the mining activities in the district from 1859 to 1924. With these two excellent histories of the district easily available, it would be useless repetition for the writer to give a detailed account of the development of the district. However, a summary of the most significant events is given here before the geology and the individual mines of the special area are considered.

A group of prospectors discovered rich placer ground on the north side of Farncomb Hill in the summer of 1859, and within the next 3 years $3,000,000 in gold was washed from the placers in Georgia Gulch, the Swan River, Gold Run Gulch, Galena Gulch, American Gulch, Humbug Gulch, Delaware Flats, the Blue River, and French Gulch and its tributaries—Gibson, Nigger, Corkscrew, Illinois, and Hoosier Gulches. In 1870 there were 100 miles of ditches and flumes in the district and $6,000,000 had been recovered from the placers. During the next 10 years the output of gold dwindled to a little less than $1,000,000, all of which came from placers. In 1880 gold was found in place on Farncomb Hill, and for the next 10 years the rich narrow veins of crystallized gold, for which the district is justly famous, yielded most of the gold output. Gold-bearing lodes were discovered in other parts of the district soon after those on Farncomb Hill were uncovered, and veins were the chief source of gold until dredging began on a large scale. Gold dredges were introduced in 1898 and have been working the deep gravel of the large gulches ever since. In the first few years of their operation they were largely experimental and did not contribute materially to the production of the district, but the construction of larger and stronger boats enabled the later dredging enterprises to work large tonnages of the coarse gravel successfully. It is probable that $7,000,000 in gold has been produced by dredging low-grade placers in the district.

The earliest attempt to mine lead-silver ores in the Breckenridge district occurred in 1869, when some argentiferous lead ore was taken from the Old Reliable vein, in French Gulch near Lincoln, about 3 miles east of Breckenridge. A small amount of lead was smelted here in 1873–75, but little interest was shown in lead veins until the completion of the railroad from Denver to Breckenridge in 1880. The advent of cheap transportation greatly stimulated lode mining, and within a few years most of the mines that have produced lead ore were developed. The first flush of production came in the late eighties and early nineties, and after this period the production of lead showed a decided downward trend until 1910. At this time the Wellington mine started active development, and it was a large and moderately steady producer of lead and zinc up to 1929. The output of this mine has made up the bulk of the lead and zinc ore shipped from the Breckenridge district in the period 1910 to 1929 and compares favorably with the large production of the district in the early nineties.

Tables showing the production of individual mines are given on pages 60–62.

GENERAL GEOLOGY

The general geology of the Breckenridge district has been discussed by Ransome,[5] and in the following pages the formations will be described only briefly unless information can be given that is not found in the earlier report.

Sedimentary rocks in the Breckenridge district include formations from the Pennsylvanian (?) to the Upper Cretaceous. Their character, approximate thickness, and relations are shown in figure 2.

As a result of detailed studies in the district and at places nearby, the writer has been able to recognize several subdivisions that have not been made in this region before. The Dakota sandstone of Ransome's report on the district and the uppermost beds of his †Wyoming formation have been divided into the Morrison formation (Upper Jurassic) and the Dakota quartzite (Upper Cretaceous). The Upper Cretaceous shale has been subdivided into the Benton shale, the Niobrara formation, and the Pierre shale. The †Wyoming formation, as previously recognized in this region, is considered equivalent to the Maroon formation of present terminology. These changes in correlation are discussed in detail under their respective headings.

Pre-Cambrian rocks are exposed in two places in the area studied, and they underlie the sedimentary rocks throughout the district. A quartz-biotite-muscovite schist is exposed at the Owl tunnel, on French Gulch, near the northwest corner of the area mapped. The foliation of this schist strikes about N. 20° W. and dips about 60° E. Schist, granite, and granite gneiss come to the surface in the upper part of Illinois Gulch, but the trend of the schistosity could not be seen. The regional strike of the schistosity, however, over a large

[3] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colorado: U.S. Geol. Survey Prof. Paper 75, pp. 17-20, 1911.

[4] Henderson, C. W., Mining in Colorado: U.S. Geol. Survey Prof. Paper 138, pp. 32-36, 227-224b, 1926.

[5] Ransome, F. L., op. cit., pp. 25-40.

area to the north, east, and south is known to be north or northwest, and the dips are consistently east or heast; thus it is probable that the foliation of the and gneiss throughout the special area of the

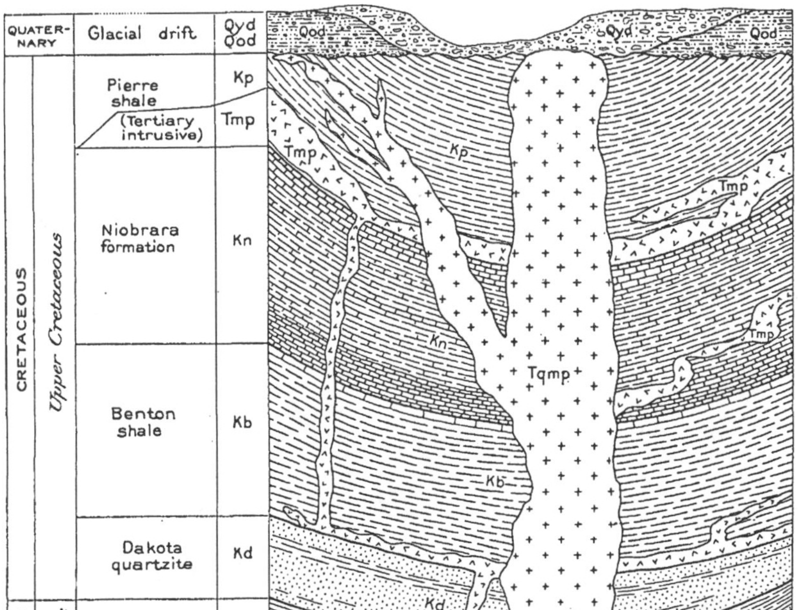


FIGURE 2.—Columnar section for Breckenridge district. Tertiary intrusives: Tqmp, Eocene quartz monzonite porphyry; Tmp, Eocene monzonite porphyry.

Breckenridge district does not deviate greatly from the strike and dip observed in the Owl tunnel.

MAROON FORMATION

Correlation.—The Maroon formation was named by Eldridge [6] in the Anthracite-Crested Butte folio.

[6] Cross, Whitman, and Eldridge, G. H., U.S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte folio (no. 9), p. 6, 1894.

He called the formation Maroon conglomerate and included in it all beds between his Weber limestone below and the unconformably overlying †Gunnison formation, and he correctly assigned to it a Carboniferous age. As defined by Eldridge, the Maroon included at the base the so-called † Weber grits, which Emmons [7] excluded from the formation in 1898 and which were thenceforth regarded as separate from the Maroon. The name †Gunnison formation is no longer used, as the rocks are equivalent to the Morrison formation, and Morrison is the older name.

In the Denver Basin the †Wyoming formation was defined by Emmons and Eldridge [8] as the beds between the pre-Cambrian rocks and the Morrison formation. It was at first assigned to the Triassic system, but later work showed that most, if not all, of the beds below the Morrison belong to the Carboniferous system. As shown in the correlation chart in plate 3, the Maroon formation, as first defined, is practically equivalent to the original †Wyoming group of the Denver Basin, on the east side of the Front Range, which has since been subdivided into the Fountain, Lyons, and Lykins formations, and the term †Wyoming is no longer used.

In the Tenmile folio Emmons [9] subdivided the Carboniferous rocks overlying the †Weber grits into the Maroon and Wyoming formations. He considered his Jacque Mountain limestone the uppermost bed of the Maroon formation and the overlying sandstone the base of the †Wyoming formation. Limestone is much less common in the †Wyoming formation, as he defined it, than in his Maroon formation, and the red color of the sandstone is more pronounced in the so-called †Wyoming than in the underlying beds. No other changes in the lithology are mentioned, and no evidence of an unconformity was found between the two subdivisions. Emmons [10] correlated the upper red sandstones in the Tenmile district with the †Wyoming of the Denver

[7] Emmons, S. F., U.S. Geol. Survey Geol. Atlas, Tenmile district folio (no. 48) 1898.

[8] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin: U.S. Geol. Survey Mon. 27, pp. 51-60, 1896.

[9] Emmons, S. F., U.S. Geol. Survey Geol. Atlas, Tenmile district folio (no. 48), 1898.

[10] Idem, p. 2.

Basin, "not because of any fossil evidence of their age that could be found, but because by their position and petrological character they most nearly correspond to the beds of this formation which elsewhere in the Rocky Mountain region have, on fossil evidence, been determined to be Triassic."

Ransome [11] says that the †Wyoming of the Breckenridge and Tenmile districts is probably the stratigraphic equivalent of the Lykins of the Boulder district (called †Upper Wyoming by Emmons, Cross, and Eldridge). The †Weber grits and Maroon of the Tenmile folio are probably equivalent in a general way to the Fountain and Lyons formations or †Lower Wyoming of the Denver Basin.

It is evident that all the beds overlying the †Weber grits in the Tenmile district are to be correlated with the Maroon formation, as now recognized in the Anthracite-Crested Butte area, and with the central and upper parts of the original †Wyoming of the Denver Basin, and that the underlying so-called Weber strata are to be correlated with the lower part of the original †Wyoming formation. The name †Wyoming is obsolete and has long been abandoned by the United States Geological Survey. The beds between the Morrison and the †Weber grits in the region south and west of Breckenridge are therefore designated Maroon formation in this report, and the underlying grits and conglomerates are called Weber (?) formation, because the equivalency of these beds to the typical Weber of eastern Utah is now seriously questioned. Because of the Permian overlap the Weber (?) formation does not show in the area mapped, but it may be present at depth in the southwestern part of the region.

Lithology.—It will be helpful to summarize the chief features of the Weber (?) and Maroon formations in central Colorado before considering their lithology in the Breckenridge district. The contact of the †Weber grits with the underlying †Weber shales is gradational in some places and sharp in others. The so-called "grits" consist of micaceous sandstone, shale, grit, and conglomerate, strongly cross-bedded and locally containing beds of limestone. The color is generally gray. The lower part of the overlying Maroon formation is commonly more calcareous than the upper part, and the predominant color is dark red. In the upper part of the Maroon formation limestone becomes rare and the dark-red color gradually gives place to a brilliant brick-red, although some beds of gray shale and sandstone are present.

Throughout the formation the grit and sandstone are strongly cross-bedded and may grade into shale or conglomerate within very short distances, both along and across the bedding. The lenticular character of the beds is a striking feature of the entire formation and is well shown in the structure-section sheets of the Tenmile folio. Most of the material in the grit and conglomerate was derived from pre-Cambrian rocks, but pebbles of limestone are common in the conglomerate near the base of the Weber (?) formation. The combined thickness of the Weber (?) and Maroon formations ranges from a few feet to nearly 10,000 feet in central Colorado and is commonly about 5,000 feet.

A short distance east of Breckenridge the Morrison and Dakota formations successively overlap the pre-Cambrian rocks, and in the district only the thin edge of the Maroon formation, from 600 to 900 feet thick, is exposed; but the beds show all the variations of lithology that the thickest sections of the Weber (?) and Maroon formations show elsewhere. The varying character is well illustrated near Gibson Hill. At the Owl tunnel the base of the formation is a thick coarse conglomerate, containing boulders as much as 2 feet in diameter, overlain by a black carbonaceous shale, which in turn is succeeded by another coarse conglomerate. This succession is typical of the lower part of the †Weber grits, near a gradational contact with the underlying †Weber shales, although the conglomerate is not generally so coarse. The lithology suggests reworked †Weber at the base of the overlapping Maroon formation. Near the Sultana mine, 1 mile to the northwest, the base of the Maroon formation is a bed of grit 2 feet thick and is overlain by a thick bed of bright-red micaceous sandy shale, such as typifies the uppermost beds of the Maroon formation. The sedimentary contact of the beds with the pre-Cambrian rocks is exposed in both places and leaves no doubt as to the rapid lateral variation that has taken place. It is impossible to give a helpful detailed section of the Maroon formation in a district where such changes have occurred. In general, the coarse conglomerate beds are more common near the base of the formation than they are near the top. Black shale, so far as the writer knows, is confined to the base of the formation. Micaceous red shale is most common in the upper part of the section. Beds of grit and sandstone are well represented throughout the formation but are not as abundant as the shale and conglomerate. A moderately persistent sandstone, varying from yellowish brown to light orange-yellow, occurs near the top of the section. Limestone beds from 2 to 5 feet thick are interbedded with shale and grit. These beds are lenticular and although confined to no definite horizon seem to be more common near the base of the formation than in the upper part. For further information on the character of the material in the grit and conglomerate and a discussion of the cause of the red color, the reader is referred to Ransome's description of the †Wyoming.[12] In the special area studied, the thickness of the Maroon formation ranges from about 600 feet in the northwestern part to about 900 feet in the southeastern part. The average thickness is probably close to 700 feet.

[11] Ransome, F. L., op. cit., p. 31.

[12] Ransome, F. L., op. cit., pp. 31-33.

The Maroon formation is well exposed along the north bank of Indiana Gulch and in the upper part of Illinois Gulch. It passes from sight beneath the younger formations in the central part of the special area and reappears in the northwestern part at the base of Gibson Hill.

Near intrusive masses and in the vicinity of metalliferous veins, the normal color and character of the formation is locally changed. The bright-red color of the Maroon sandstone and shale may be reduced to greenish gray near a vein, and garnet, epidote, and other contact-metamorphic minerals are common in the calcareous beds near certain bodies of quartz monzonite porphyry.

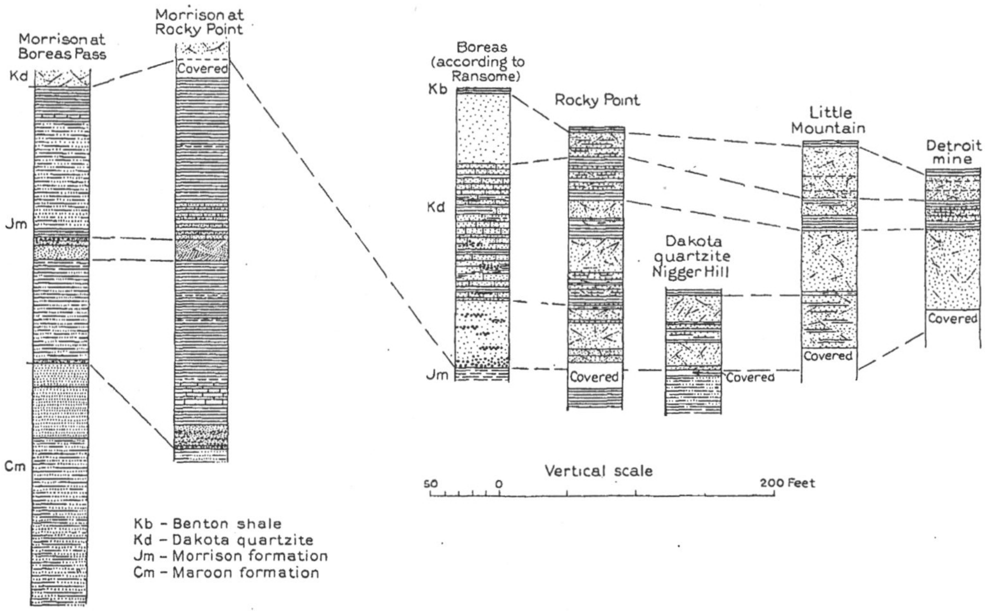


FIGURE 3.—Correlation of sections measured from Boreas Pass to Keystone.

MORRISON FORMATION

Correlation.—The Morrison formation (now classified as Upper Jurassic) is widely distributed in the region surrounding Breckenridge. It has not hitherto been separated from the overlying or underlying beds, but in the detailed study of a small area it was found possible and helpful to make the Morrison a distinct cartographic unit. Although Ransome [13] recognized the probability that the Morrison was present in the district, he did not find sufficient evidence to map it as an individual formation and included most of it with the Dakota quartzite. The uppermost beds of his †Wyoming and the lower part of his Dakota, specifically those beds below bed 5 in his Rocky Point section, are included by the present writer in the Morrison. This formation underlies the Dakota quartzite everywhere in the Breckenridge district. Nearly the entire thickness of the Morrison formation can be seen at Rocky Point, but its lower part is poorly exposed and is separated from the overlying part by a thick porphyry sill. No other place in the district, however, shows so much of the formation. Its shaly character makes it weather into smooth slopes, and only where man or some accident of erosion has cut into it, are exposures found. It is well represented in the fault mosaic of Gibson Hill and forms the lower slopes of Little Mountain and the southern slope of Nigger Hill, but very few outcrops can be found in these localities.

The Morrison can be traced from the Breckenridge district through the knob south of Boreas Pass into the Tarryall district, where Muilenberg [14] found fossils of Morrison age.

Lithology.—Its lithology is extremely varied in detail, but the following sections are typical in the Breckenridge district and are graphically correlated in figure 3.

Section of Morrison formation near Rocky Point

	Feet
Dakota quartzite. Base of the Dakota concealed; light-gray pebbly quartzite carrying fragments of shells in float between outcrops of unquestionable Dakota and the red shale; base assumed to be 5 feet below outcrop.	
Covered	20
Morrison formation:	
Red shale, thin-bedded, not micaceous	12
Blue-green and olive-green shale, thin-bedded, locally with pinkish layers	35
Thin-bedded and blocky shales, brownish purple and maroon; some layers weather gray	43
Hard limy and sandy dark-gray medium-bedded shale, alternating with thin-bedded purplish-brown shale	26

[13] Ransome, F. L., op. cit., pp. 34, 36.

[14] Muilenberg, G. A., Geology of the Tarryall district, Park County, Colo.: Colorado Geol. Survey Bull. 31, p. 21, 1925.

Section of Morrison formation near Rocky Point—Continued

	Feet
Morrison formation—Continued.	
Massive grayish-white cross-bedded gritty sandstone; numerous brown spots and discontinuous brown bands a quarter of an inch wide	15
Thin-bedded shale, brownish, maroon, and black; mostly covered	25
Very thin-bedded gray and brown shale	18
Massive and medium-bedded gray shale; weathers buff	45
Thin-bedded limy shale and shaly limestone, grayish-green; weathers buff	6
Massive grayish-green limestone; color probably caused by metamorphism of underlying porphyry sill; both epidote and hematite are developed on joint surfaces	12
Porphyry sill about 450 feet thick separates the limestone above from the remainder of the section, which is very poorly exposed.	
Light-red nonmicaceous thin-bedded shale, about	15
Medium-bedded medium-grained white sandstone containing many layers of grit and a few layers of conglomerate. The sandstone contains conspicuous rusty blotches a quarter to half an inch in diameter. The conglomerate contains pebbles of micaceous red shale and pre-Cambrian pegmatite from half to three quarters of an inch in diameter in a matrix of light-colored quartz grit. About	15
Conglomerate, largely made up of pebbles of micaceous red shale about half an inch in diameter in a matrix of pink sand	2
Red micaceous shale (Maroon formation).	284

Section half a mile west of Boreas Pass

	Feet
Dakota quartzite. Hard medium-grained light-gray cross-bedded quartzitic sandstone and grit.	
Morrison formation:	
Thin-bedded red shale	22
Light purple limestone	1
Thin-bedded sandy red shale	80½
Porphyry sill, 14½ feet thick.	
Thin-bedded maroon shale	5
Coarse-grained brownish grit	3
Coarse-grained white gritty sandstone	3
Conglomeratic quartz grit	10
Thin-bedded nonmicaceous red sandy shale, with a few thin beds of grit	75
Arkosic sandstone and conglomerate; contain pebbles of micaceous red sandstone and micaceous red shale	2
Total thickness of Morrison	201½
Maroon formation:	
Thin-bedded fine-grained arkosic pink sandstone	20
Thin-bedded coarse-grained light-gray sandstone	35
Thin-bedded micaceous reddish-brown sandy shale	200

In the Breckenridge district the Morrison formation is commonly made up of a gritty sandstone overlain by a series of beds of dark-gray and maroon shale containing local limy beds, which in turn are overlain by a very persistent cross-bedded sandstone (no. 8 in Ransome's Rocky Point section; nos. 3–5 in his Boreas section); the remainder of the formation consists chiefly of gray and maroon shale, some of which is decidedly calcareous. The character of the formation in the northeastern part of the special area differs somewhat from that of the sections given above. In that locality the upper part of the formation contains thin lenticular beds of grit and sandstone and a bed of limestone interbedded with shale that is generally light gray and very thin-bedded. At the base of the formation there is generally a bed of gray gritty quartzite about 20 feet thick.

The micaceous appearance of the shale and sandstone of the Maroon formation is one of the most outstanding characteristics, and the shale of the Morrison may be easily distinguished from that of the Maroon by its complete lack of visible mica. Shale of the Morrison having a reddish tinge will not be confused with that of the Dakota, which is gray or black, but the gray shale of the two formations is indistinguishable. The sandstone of the Morrison is generally softer, coarser-grained, and more cross-bedded than similar beds in the Dakota quartzite.

The limy beds of the Morrison are completely converted into garnet, epidote, magnetite, hematite, and other contact-metamorphic minerals on Prospect Hill, just west of the Wellington mine. On the south slope of Gibson Hill contact-metamorphic minerals have been developed at the same horizon. More detailed consideration of the contact metamorphism of these beds is given on pages 16–17.

DAKOTA QUARTZITE

The *Dakota quartzite* is well represented in the Breckenridge district and is one of the most persistent and easily recognized formations present. The best section of the Dakota was found at Rocky Point, which is the only place in the district where there is a continuous exposure of the rocks from the Morrison to the Benton. At Nigger Hill and Little Mountain there are good sections of the massive lower quartzite member, and the upper quartzite is well exposed in the open pits on the Puzzle-Ouray vein, nearby. The shaly middle member of the formation is not well exposed at any place other than Rocky Point, although it can be recognized on Little Mountain and in the underground workings on Gibson Hill.

Lithology.—The three members recognized by Ransome [15] at Boreas Pass, 5 miles southeast of Breckenridge, can also be recognized in the district. The most significant changes noted in following the beds to the northwest are the loss of the light-red color of the middle shaly member and the transition from a sandy and shaly limestone to carbonaceous shale and quartzite. Evidently a similar change occurs east and southeast of Boreas Pass, for, according to Muilenberg: [16]

[15] Ransome, F. L., op. cit., p. 35.

[16] Muilenberg, G. A., Geology of the Tarryall district, Park County, Colo.: Colorado Geol. Survey Bull. 31, p. 26, 1925.

On the east side of the pass this section cannot be recognized. * * * No evidence was found of the sandy limestones which are there encountered, although the dark shale is probably present, as are the conglomeratic beds.

Between Dillon and Keystone, 11 miles north of Breckenridge, the three members of the formation can be recognized and show the same characteristics as at Breckenridge. It therefore seems probable that the Boreas Pass section represents an unusual facies of the formation and that its general character is well illustrated in the Rocky Point section, which is given below. However, the middle member differs greatly in thickness and in the details of its lithology within short distances, and the formation as a whole thins rapidly eastward. At Georgia Pass, 4 miles northeast of Boreas Pass, the overturned sedimentary contact between the Dakota and the pre-Cambrian rocks is well exposed. At this locality there is no faulting between the quartzite and the underlying schist or the overlying black shale beds, which are more than 200 feet thick. The shale is probably Benton, yet the quartzite here is only 20 feet thick. The regional structure indicates that the beds now exposed at Georgia Pass were probably deposited at least 7 or 8 miles northeast of the exposures at Boreas Pass and that folding has brought these distant parts of the formation within 4 miles of each other. The distinct northeastward thinning of the Dakota probably marks the overlap of the formation on the slowly submerging pre-Cambrian highland, which the writer believes had been a source of sediments for the Weber (?), Maroon, and Morrison formations.[17]

The thickness of the Dakota in the region discussed above ranges from 225 to 20 feet, but in the special area of the Breckenridge district the thickness ranges from about 125 feet on Gibson Hill to 175 feet at Rocky Point. Detailed sections at various localities are given below and are graphically correlated in figure 3.

Section of the Dakota quartzite near Boreas Pass

[After Ransome]

	Feet
3. Massive, buff, fine-grained sandstone	50
2. Thin-bedded reddish and gray sandy limestone with some pebbly grit and a little dark shale. Weathers pink or light red as a whole	100
1. Light or buff sandstone with pebbly streaks. Beds thinner than no. 3. Bottom bed, about 6 feet thick, contains abundant pebbles of white quartz, mostly less than half an inch in diameter. This bed ranges from coarse sandstone to fine conglomerate	50
	200

[17] Lovering, T. S., Geologic history of the Front Range, Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 81-86, 1929.

Section of the Dakota quartzite at Rocky Point

[By T. S. Lovering]

	Feet
Benton shale: Black shale.	
Dakota quartzite:	
Upper member:	
Medium-bedded light-gray quartzite with a few black-shale partings	12.5
Massive, moderately fine grained, slightly banded light-gray quartzite, heavily stained with limonite	5.5
Thickness of upper member	18
Middle member:	
Gray shale	1.5
Medium-grained gray quartzite	.8
Dark-gray to black shale	2.5
Thin bedded light-gray quartzite and gray shale	3.5
Black shale	2.5
Thin-bedded black shale and gray quartzite	4.5
Black shale	4.5
Thin-bedded dark-gray shale and quartzite	5
Grayish-white quartzite	2.5
Grayish-black shale	.5
Grayish-white quartzite	.5
Brownish-black coaly shale, containing marcasite and carbonized plant remains	2.5
Massive, medium-grained gray quartzite, gritty at bottom with pitted surface at base	13
Black shale	.5
Massive, moderately fine grained light-gray quartzite	5
Black coal-bearing shale	2
Dark-gray shaly quartzite	.5
Thin-bedded gray shale and quartzite	1
Medium-bedded dark-gray banded quartzite	2.5
Sandy gray shale	2
Thickness of middle member	59.3
Lower member:	
Massive, moderately fine grained grayish-white quartzite, slightly banded at the base	26
Medium-bedded black quartzite and black shale	5
Medium and fine grained dark-gray quartzite	2
Black shale	1
Thin-bedded grayish-white fine and medium grained quartzite, containing white chalky lines suggesting shell fragments	4
Alternations of 8-inch beds of black shale and quartzite	5
Black shale	5
Buff quartzite	.5
Sandy gray shale	3
Massive medium-grained gray quartzite	10
Grit, containing chalky marks suggesting shell fragments	.5
Thin-bedded, finely banded buff and grayish-white sandy quartzite	20
Massive coarse-grained grit and quartzite, containing pebbles half an inch in diameter	5

Section of the Dakota quartzite at Rocky Point—Continued

	Feet
Dakota quartzite—Continued.	
Lower member—Continued.	
Massive fine-grained light-gray sandy quartzite; carries many plant remains preserved in limonite	5
Covered	20
Thickness of lower member of the Dakota, base assumed 5 feet below covered portion between sandy quartzite and the red shale	97
Total thickness of the Dakota	174.3
Morrison formation (red fissile shales, not micaceous)	12

Partial section of Dakota quartzite in the Detroit mine, Gibson Hill

	Feet
Benton shale: Black shale.	
Dakota quartzite:	
Upper member:	
Massive dark-gray quartzite	3
Massive gray quartzite	7
Thin-bedded gray quartzite	8.5
Thickness of upper member	18.5
Middle member:	
Black shale	4
Gray quartzite	2
Sandy gray shale	4
Light-gray quartzite	4.5
Banded gray shale	4.5
Thickness of middle member	19
Fault.	
Lower member: Gray quartzite to bottom of shaft	60

Section of the Dakota 1 mile west of Keystone

	Feet
Benton shale: Gray shale.	
Dakota quartzite:	
Upper member:	
Medium-bedded gray quartzite	10
Thin-bedded gray quartzite	5
Massive light-gray quartzite	32
Thickness of upper member	47
Middle member:	
Black shale	13
Massive gray quartzite	4
Black shale	1
Massive quartzite	25
Interbedded black shale and gray quartzite	50
Thickness of middle member	93
Lower member:	
Massive gray sandy quartzite	16
Hard massive gray quartzite	69
Thickness of lower member	85
Thickness of the Dakota	225
Green shale of the Morrison.	

Section of Dakota quartzite on Little Mountain

	Feet
Benton shale: Black shale.	
Dakota quartzite:	
Upper member:	
Massive light-gray quartzite	10
Thin-bedded banded light and dark gray quartzite	10
Massive banded light and dark gray quartzite	12
Massive black quartzite	5
Thickness of upper member	37
Middle member:	
Thin-bedded black shale and quartzite	6
Massive white sandy quartzite	7
Limy gray shale	10
Thickness of middle member	23
Lower member:	
Massive grayish-white quartzite	45
Gray shale	3
Massive grayish-white quartzite with a few gray-shale partings	40
Thickness of lower member	88
Covered.	
Total thickness exposed	148

Partial section of the lower member of Dakota quartzite exposed on Nigger Hill

	Feet
Gray quartzite	2
Gray shale	3
Massive medium and coarse grained grayish-white quartzite	20
Gray shale	1
Massive gray quartzite	3
Gray shale	2
Medium-bedded light-gray quartzite with shaly partings, some of which contain plant fragments	6
Light-gray sandstone	1
Massive grayish-white quartzite, darker at base	19
Massive light-brown sandy and gritty quartzite	3
	60
Morrison formation: Greenish-white, brownish-green, and reddish-brown shale	13

A consideration of the detailed sections given above and the graphic correlation chart shown in figure 3 should give the reader an understanding of the general character of the formation. The three members may be clearly distinguished at Rocky Point, where differential weathering of the steeply dipping formation has served to accentuate the essential unity of the individual members. From the flats south of Little Mountain the Rocky Point exposure stands out prominently and appears to consist of three beds—a thick hard light-colored basal bed, a softer black middle bed, and a thin light-colored top bed. As the Dakota is the most significant key formation of the district, its lithology is worth careful study, and the following summary may be helpful to anyone working in this region.

The lower member is predominantly massive light-gray quartzite and ranges in thickness from 95 to 120 feet. Gritty or conglomeratic beds are usually found near the base, and a few thin beds of gray or, less commonly, black shale are nearly everywhere present. The shale beds are not persistent and may thin and disappear in short distances.

The middle member is the most variable of the three in thickness as well as in lithology. It contains more shale than any other part of the formation, but the individual shale beds are lenticular and can seldom be correlated with any confidence. Both black and gray shale beds are common, and the quartzite beds belonging to this member are more generally dark colored or black than those in other parts of the formation. A bed of shale may grade within a short distance through sandy shale into quartzite, or it may thin from a 5-foot bed to a shale parting within a few hundred feet. The variation in color, thickness, and composition of the individual beds in this member makes it difficult to estimate the stratigraphic position of isolated or small exposures of interbedded shale and quartzite. The thickness of the middle member ranges from 20 to 60 feet and is greatest in the southern part of the district.

The upper member of the Dakota (pl. 4, *A*) is the least variable of the three. It consists of massive and thin-bedded light-colored quartzite, having a few shale partings, and is commonly from 20 to 30 feet thick in the special area. The lower part of the Benton shale contains thin beds of black quartzite at some places near Breckenridge, but the contact of the two formations is clearly marked.

No identifiable fossils were found in the Dakota quartzite by either Ransome or the writer, although plant fragments are abundant at certain horizons in several localities. Its lithologic character and its presence immediately below beds of definite Benton age leave no doubt as to the propriety of correlating it with the Dakota sandstone of central and eastern Colorado.

BENTON SHALE

Correlation.—The Benton shale has not heretofore been mapped as a separate unit in the Breckenridge district or the surrounding region. Its presence was recognized by Ransome [18] and by Muilenberg, [19] but no attempt was made to establish the thickness of the formation. Benton fossils have been found at many localities west of the Front Range, and it is evident that the Benton shale is persistent for long distances to the north, west, and south of Breckenridge, but comparatively little study has been accorded it

[18] Ransome, F. L., op. cit., p. 38.
[19] Muilenberg, G. H., op. cit., p. 27.

in this region. Spurr [20] found 350 feet of black calcareous shale of Benton age underlying the Niobrara limestone at Aspen, 50 miles west of Breckenridge. Eldridge [21] found 150 to 300 feet of black shale and interbedded fetid limestone of Benton age in the Anthracite and Crested Butte quadrangles, 60 miles southwest of the Breckenridge district. The Benton fauna found in the Tarryall district by Muilenberg was in a black bituminous shale and associated beds of fetid limestone immediately over lying the Dakota quartzite.

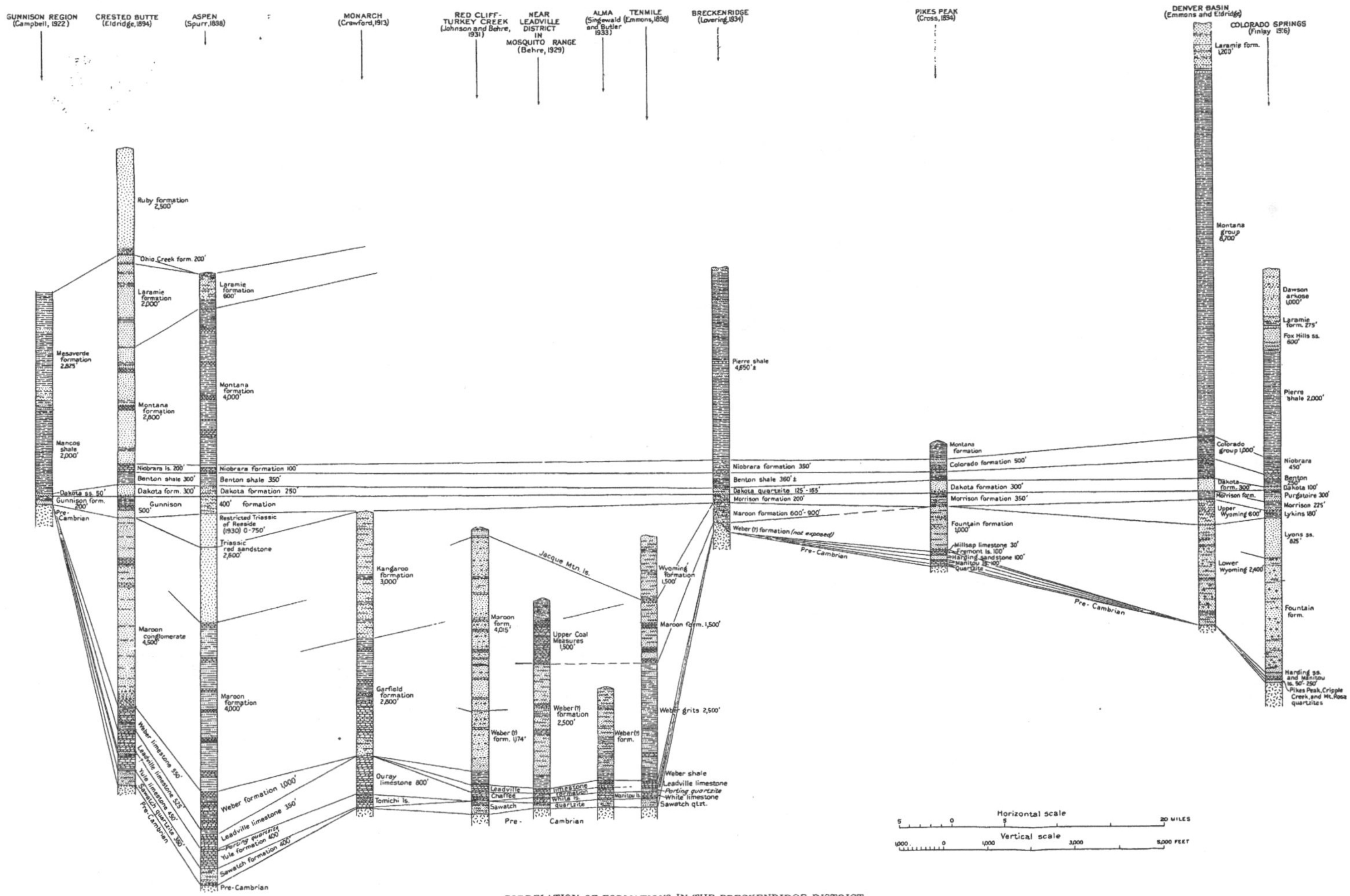
Henderson [22] assigns a thickness of 300 to 400 feet to the Benton in the Rabbit Ear district and in the vicinity of Kremmling. According to drill records obtained near Walden, the Benton is 550 feet thick in that part of North Park, but Beekly [23] gives the thickness as only 165 feet.

Lithology.—There are no localities in the Breckenridge district where a complete section of the Benton shale was found. The information regarding thickness and lithology was pieced together from many incomplete exposures, supplemented by study of the region north of the district. The average thickness of the shale is probably very close to 360 feet, but the complex faulting and intense intrusive activity that have occurred in the district, together with the lack of outcrops, makes it difficult to give a confident estimate of the thickness.

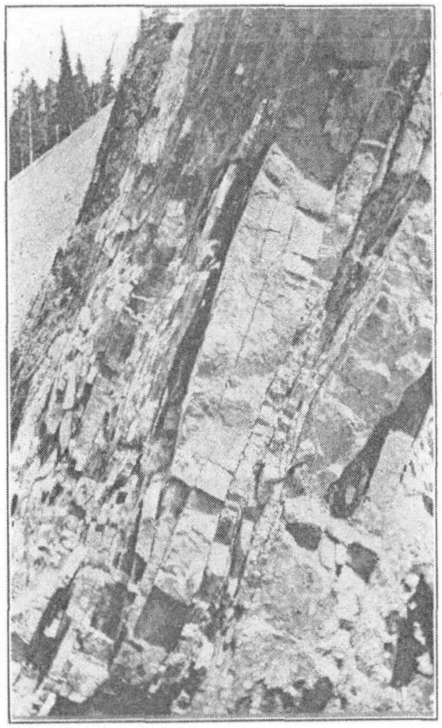
The best section found is in the railroad cut just northeast of Rocky Point. At this locality nearly 300 feet of the Benton shale is exposed, by far the most continuous section in the district, and although the beds have been disturbed by quartz monzonite porphyry intrusions and locally overturned, the general character of the section can be easily determined. The uppermost part of the section can be seen at the railroad cut on Nigger Hill, at the north end of the trestle crossing Illinois Gulch.

Throughout the district the Dakota quartzite is overlain by black shale for 30 to 50 feet. Between the lower black shale and a point about 250 feet above the quartzite, the shale usually has a decided grayish cast, varying from dark gray to grayish black; the shale up to this place in the section is rather fissile. Thin-bedded black shale and limestone alternate for about 35 feet above the grayish-black shale and are overlain by about 50 feet of black fissile shale. Capping the black fissile shale is a bed of shaly limestone about 25 feet thick. It is a fetid black fossiliferous limestone, probably the equivalent of the †Nio-Benton sand of the oil-well drillers of North Park, as it forms the top of the Benton shale and the base of the Niobrara formation.

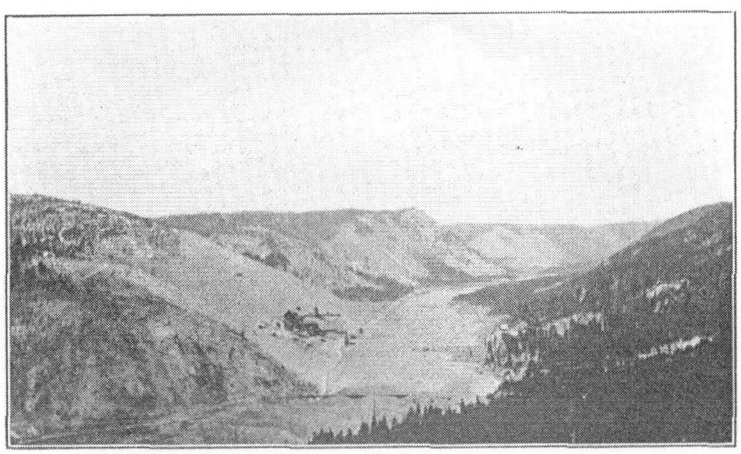
[20] Spurr, J. E., Geology of the Aspen mining district, Colo.: U.S. Geol. Survey Mon. 31, p. 41, 1898.
[21] Eldridge, G. H., and Cross, Whitman, op. cit., p. 6.
[22] Grout, F. F., Worcester, P. G., and Henderson, Junius, Geology of the Rabbit Ear region: Colorado Geol. Survey Bull. 5, p. 31, 1913.
[23] Beekly, A. L., Geology and coal resources of North Park, Colorado: U.S. Geol. Survey Bull. 596, p. 36, 1915.



CORRELATION OF FORMATIONS IN THE BRECKENRIDGE DISTRICT.



A. UPPER MEMBER OF DAKOTA QUARTZITE.



B. VIEW LOOKING EAST UP FRENCH GULCH FROM NORTH SLOPE OF NIGGER HILL.

There is no break evident between the Benton and Niobrara, and Niobrara fossils have been obtained from the shale at the top of the limestone that yields typical Benton forms. Near Keystone, 11 miles to the north, Niobrara fossils were found in a limestone immediately overlying a black fetid unfossiliferous limestone 370 feet above the Dakota quartzite. The break between the Dakota and the Benton is usually abrupt, but in some localities there is a transition zone in which thin beds of quartzite alternate with black shale through a distance of about 10 feet. Near Dillon the base of the Benton is marked by a thin bed of conglomerate containing fragments of Dakota, Morrison, and pre-Cambrian formations. The sections of the Upper Cretaceous shale given in figures 3 and 4 show the general relations of the Benton to the other Cretaceous formations.

The Benton shale, in common with the other sediments of the district, may be greatly altered by intrusive rocks, and this subject is considered under the heading "Rock alteration" (pp. 16–17).

In the special area of the Breckenridge district the largest exposure of Benton shale occurs in the syncline between Little Mountain and Rocky Point. The shale underlies the Niobrara formation in French Gulch and elsewhere and crops out on the top of Gibson Hill.

NIOBRARA FORMATION

The stratigraphic limits of the Niobrara formation cannot be worked out from the exposures in the Breckenridge district, nor can the lithology of the formation be satisfactorily established. A study of the sections between Dillon and Keystone, a reconnaissance of the region from Breckenridge to North Park, and detailed work on the exposures in the special area form the basis of the conclusions presented here.

In the Anthracite-Crested Butte area the Niobrara limestone consists of a limestone bed about 30 feet thick overlain by approximately 150 feet of calcareous gray shale. At Aspen the Niobrara limestone is said to be about 100 feet thick and to grade upward into the Montana shales without any perceptible break. In North Park, according to Beekly,[24] the average thickness of the Niobrara formation is about 800 feet. Well records in the park later confirmed this estimate. The formation in this region, as well as in the country to the south, is made up of a basal thin-bedded limestone overlain by interbedded calcareous and clay shale and locally capped by a thin limy sandstone.

In the Keystone section measured by the writer (fig. 4) the calcareous beds definitely assignable to the Niobrara are 350 feet thick, but it is possible that a thin limy layer in the overlying blue-black clay shale carrying poorly preserved fragments of *Hypsodon*, *Ostrea*, and *Baculites* may mark the top of the formation, suggesting a possible thickness of about 475 feet. No fossils were found in the nearly uniform succession of somber-colored clay shale overlying this layer for nearly 1,500 feet. The present lack of fossil evidence that the clay shale belongs to the Niobrara and the decided change that occurs in lithology make it advisable to limit the Niobrara formation to the calcareous beds. In the Breckenridge district the upper limit of the formation is placed at the top of the calcareous beds 350 feet above the Benton. This calcareous zone in the Cretaceous is widely distributed in the region around Breckenridge and is nearly uniform in thickness and in general lithology. It carries Niobrara fossils in many localities and is undoubtedly of Niobrara age from top to bottom and is overlain by thick somber-colored clay shale.

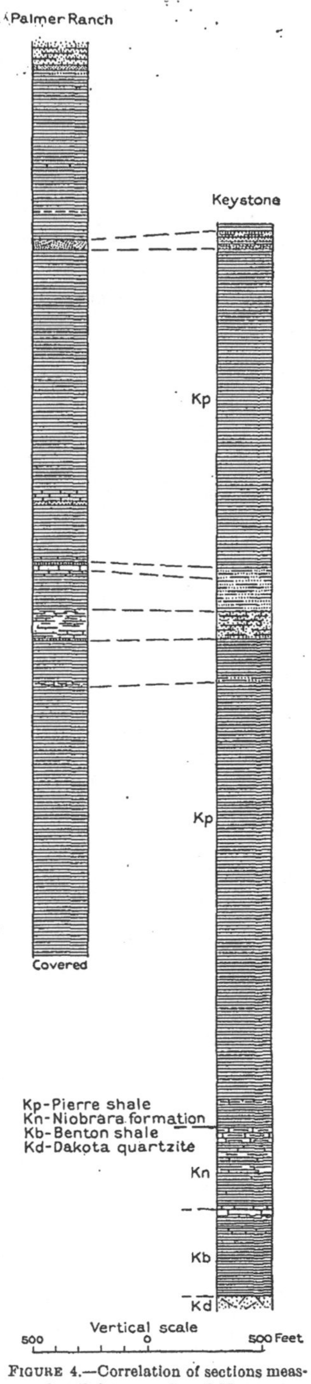


FIGURE 4.—Correlation of sections measured at Palmer ranch and Keystone.

The Niobrara is well exposed in the Wellington mine and in some prospects in Illinois Gulch. The formation has its greatest areal extent in the syncline between Little Mountain and Rocky Point and is also well developed in French Gulch near the Wellington mine.

A section of the Niobrara formation near Keystone is shown in figure 4, and a composite section of the formation as it occurs in the special area is given below:

Composite section of Niobrara formation in special area

Pierre shale: Black noncalcareous clay shale.

Niobrara formation:

	Feet
Black limy shale and thin-bedded limestone containing abundant lenses and veinlets of secondary white calcite	50

[24] Beekly, A. L., op. cit., p. 39.

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Composite section of Niobrara formation in special area—Contd.

Niobrara formation—Continued.	
Gray and black limy shales with some interbedded noncalcareous clay shale	250
Massive greenish-gray limy shale, locally grading into gray limestone at the base	50
	350
Benton shale: Black fetid limestone.	

Ransome found imperfectly preserved specimens of *Inoceramus deformis* in the basal limy bed of the Niobrara 1,500 feet southeast of the summit of Little Mountain, close to a railroad cut. The following fauna was collected by the writer from the basal limestone of the Niobrara formation near Keystone and was identified by J. B. Reeside, Jr.:

Inoceramus aff. I. subquadratus Schluter
Ostrea aff. O. congesta Conrad
Baculites sp.
Globigerina sp.

PIERRE SHALE

The widespread blanket of Upper Cretaceous shale that covers most of Colorado is well developed on both sides of the Continental Divide near Breckenridge. Large portions of South Park, Middle Park, and North Park are underlain by shale of Montana age, and the shale overlying the Niobrara formation at Breckenridge can be traced down the Blue River to Middle Park and thence up Muddy Creek into North Park. No detailed work has been done on these shales in either South Park or in Middle Park, but according to Beekly [25] the Pierre shale in North Park was definitely identified and is about 4,500 feet thick. It is predominantly dark olive-gray shale but contains a few thin beds of limy sandstone; in general its lithology is similar to that of the shale of Montana age exposed along the Blue River from Breckenridge to Kremmling. In the Aspen district the shale of Montana age was estimated to be about 4,000 feet thick by Spurr,[26] but in the Anthracite and Crested Butte quadrangles, a short distance south of Aspen, Eldridge [27] found a maximum thickness of 2,800 feet.

Ransome did not subdivide the Cretaceous in the Breckenridge district and estimated that the shale present had a thickness of at least 3,500 feet and probably as much as 5,500 feet, but the presence of an unrecognized overturned isoclinal fold in the wash-covered region of the eastern part of the district caused the duplication of some shale and made the latter amount somewhat excessive for the district. As pointed out by Ransome,[28] the thickness of the shale can be best estimated by a study of the little-disturbed exposures about 10 miles down the Blue River. In figure 4 are shown the sections made by the writer at Keystone and at the Palmer ranch, about 20 miles below Dillon, and they indicate that at least 4,750 feet of Pierre shale overlies the Niobrara formation. The greatest thickness of Pierre known in the Breckenridge district occurs in the southeastern part, where there may be as much as 3,500 feet, with due allowance for the overturned fold and local faulting.

In the special area the Pierre shale does not exceed 500 feet in thickness. It is uniformly thin-bedded black or dark olive-gray noncalcareous clay shale, containing no fossils and no beds distinguishable through differences in color or in lithology. The following sections show the character of the Pierre shale some distance north of Breckenridge and are presented here in the hope that they may be of use to anyone working in the district outside of the special area considered.

Section of Cretaceous on north side of Snake River at Keystone, 11 miles north of Breckenridge

	Feet
Pre-Cambrian schist thrust-faulted onto Pierre shale.	
Pierre shale:	
Black fissile shale	20
Black sandy shale	10
Greenish-gray limy sandstone	25
Dark-gray sandstone	15
Interbedded shaly gray sandstone and shale	30
Black and dark olive-gray shale	1, 400
Thin-bedded greenish-gray sandy shale	200
Thin-bedded fossiliferous limy brownish-gray sandstone, ridge-forming member	120
Fissile gray limy shale	150
Thin-bedded hard sandy and limy shale	30
Thin-bedded to fissile black, dark olive-gray, and dark-brown clay shale	1, 850
Thin-bedded slightly limy brown shale containing fossil fragments, interbedded with blue-black noncalcareous shale	10
Blue-black fissile clay shale	115
	3, 975
Niobrara formation:	
Blue-gray thin-bedded limy shale containing abundant secondary calcite	30
Fissile blue-black limy shale, containing several beds of coarse gray limestone 1 to 2 inches thick	30
Fissile gray limy shale, separated from overlying bed by 3-inch layer of white calcite	40
Thin-bedded shale, largely covered	240
Dark grayish-black thick-bedded, dense fossiliferous limestone	10
	350
Benton shale:	
Thin-bedded bluish-gray limestone, grading downward into thin-bedded purplish limy shale	30
Covered but mostly black shale	340
	370
Dakota quartzite:	
Massive and medium-bedded fine-grained gray quartzite	47

[25] Beekly, A. L., op. cit., pp. 43-49.
[26] Spurr, J. E., op. cit., p. 43.
[27] Cross, Whitman, and Eldridge, G. H., op. cit., p. 6.
[28] Ransome, F. L., op. cit., p. 40.

Section of Cretaceous shale exposed at and above Palmer ranch, on northeast side of Blue River about 20 miles northwest of Dillon

Pre-Cambrian gneiss faulted onto the Cretaceous rocks.	
Pierre shale:	Feet
Dark-gray limy sandstone	100
Massive soft white sandstone	25
Dark sandy shale	25
Black fissile shale	400
Dark-gray limestone	2
Black fissile shale	200
Gray fissile shale	118
Medium-bedded fossiliferous, cross-bedded light-brown sandstone	50
Dark shale containing a few thin limy layers near base	1, 100
Thin-bedded brown sandy limestone with thin shale partings	25
Dark-gray shale	225
Medium-bedded gray limy shale	10
Thin-bedded dark-gray shale	10
Thin-bedded, slightly oolitic limy sandstone	10
Thin-bedded grayish-brown limestone	10
Medium-bedded light-brown limestone, cliff-forming	15
Grayish-black limy thin-bedded shale	15
Medium-bedded brown shaly limestone; cliff-forming member	10
Thin-bedded black shale	150
Thin-bedded limestone and dark-gray limy shale	125
Medium-bedded light-brown sandy limestone	10
Fissile grayish-black shale	180
Thin-bedded gray sandy limestone, with shale partings; cliff-forming member	20
Fissile grayish-black shale with a few ¼-inch layers of limestone at the base	1, 160
	3, 995
Covered by river gravel.	

The correlation of these two sections is indicated in the graphic sections shown on figure 4. The following table shows the fossils found in making the sections and their distance above the Niobrara. The fossils were identified by J. B. Reeside, Jr.

Keystone:	Feet
Baculites ovatus Say var. haresi Reeside	2, 600
Clionia sp	2, 300
Inoceramus sagensis Owen	2, 300, 2, 200
Mactra aff. M. nitidula Meek and Hayden	2, 200
Inoceramus barabini Morton	3, 930, 2, 200
Baculites ovatus Say	2, 200
Palmer ranch:	
Ostrea cf. O. larva Lamarck	4, 600
Inoceramus aff. I. barabini Morton	3, 850
Pteria linguaeformis Evans and Shumard	3, 850
Protocardia subquadrata Evans and Shumard	3, 850
Dentalium gracile Evans and Shumard	3, 850
Baculites ovatus Say	2, 150–2, 750
Baculites compressus Say?	2, 150, 2, 750, 3, 850
Inoceramus sagensis Owen	2,150, 2,750, 3,850, 4,600, 4,750
Vanikoro sp	1, 650
Fish scale	1, 650

QUATERNARY GRAVEL

The Quaternary deposits of the Breckenridge district were not mapped by the writer, as they were carefully studied and mapped by Ransome,[29] and the reader is referred to his report for a map and a comprehensive discussion of them. The materials deposited by the ice and streams of the Quaternary period may be classified as early glacial, late glacial, and Recent deposits. It is very difficult, however, to make age distinctions in the various kinds of soil and slope wash covering the hills between the valley deposits.

Early glacial deposits.—The high-terrace gravel deposited by the streams of the early glacial stage is well developed on both sides of the Blue River from a point about a mile south of Breckenridge north to Dickey and is well shown on the spur east of Breckenridge between French Gulch and the Blue River, where the deposits are over 250 feet above the present stream channels. Ransome reports that west and southwest of Breckenridge they probably attain altitudes of 650 feet above the Blue River.

The terrace-gravel deposits are made up chiefly of well-rounded boulders and pebbles and contain very little fine sand or clay. The largest boulders are about 4 feet in diameter, but most of them are less than 15 inches. Quartzite, porphyry, granite, and schist are the most common materials but are intermingled with micaceous red grit, red shale, and black shale. Most of the fragments of these formations are deeply weathered, and generally the boulders of granite, gneiss, and red sandstone readily go to pieces under the hammer.

The older slope wash contains a much larger proportion of admixed soil than the high-terrace gravel, and the fragments of bedrock are much more angular and as a rule are less weathered.

Late glacial deposits.—The moraines of the late glacial stage are well exposed on the Blue River about half a mile above Breckenridge. Moraines are also present in French Gulch a short distance below Lincoln and can be found in most of the other valleys that head in the high mountains. The extensive flats about 15 or 20 feet above the level of the present streams are composed of the outwash gravel from the last glaciers. These low-level gravel deposits are about 90 feet thick at Breckenridge and gradually decrease to about 60 feet near the mouth of the Swan River. The terminal moraine rises about 80 feet above the low-level gravel at the north end of Little Mountain, and its thickness must be at least 170 feet in this region.

All the bedrock formations are represented in the pebbles and boulders of the late glacial deposits and are usually fresh and unweathered. The largest boulders in the low-level terraces near Breckenridge are about 6 feet in diameter, but the maximum size decreases steadily downstream. The material in the low-level terraces is very poorly sorted, and there is little evidence of stratification in any of the exposures.

The writer has elsewhere presented evidence for correlating the early glacial gravel of the Front Range with the Yarmouth deglaciation of the central United States,[30] and the late glacial deposits have long been correlated with the Wisconsin glacial stage.

[29] Ransome, F. L., op. cit., pp. 72–80.

[30] Lovering, T. S., op. cit., pp. 104–106.

Recent deposits.—The postglacial deposits consist chiefly of small alluvial fans, lake beds, stream alluvium, and slope wash. In the steep-walled glacial valleys tributary streams have formed small alluvial fans at many places. Here and there in the terminal moraines and the ground moraines poorly drained hollows are the sites of swampy lake beds. The most extensive of these is the swampy meadowland known as the Goose Pasture, about 2 miles south of Breckenridge. The flood-plain deposits of the present streams are areally insignificant, but narrow belts of alluvium, generally covered with willow thickets, occur at many places along the watercourses of the district. Slope wash of recent age is almost confined to the lower slopes of the valley sides, where post-Yarmouth erosion has exposed new bedrock surfaces.

All the recent deposits are thin and discontinuous. The sorted material ranges from fine lake silts through the coarse sand of the stream deposits to the coarse gravel of the fans. The recent slope wash is indistinguishable from the older slope wash and consists of subangular rock fragments in a generous admixture of soil.

IGNEOUS ROCKS

GENERAL FEATURES

The igneous rocks in the Breckenridge district are monzonitic porphyries. In common with the intrusive rocks of the nearby mining districts, most of the porphyry is close to a true monzonite in composition, but both silicic and calcic facies are common. The silicic facies or quartz monzonite porphyry is more abundant than the calcic or dioritic facies. Ransome [31] recognized three main types—(1) the silicic type, exemplified by quartz monzonite porphyry with phenocrystic quartz and orthoclase; (2) the calcic type, exemplified by monzonite porphyry grading into diorite porphyry, with only incidental quartz in the groundmass; and (3) the intermediate type, which lacks orthoclase phenocrysts but in which quartz is commonly present as phenocrysts.

Ransome did not find it practicable to attempt the separate mapping of the intermediate type in the time available. Although the structural relations of these porphyries to one another were obscure, he concluded, on the basis of the scant evidence then available, that the porphyries on the whole were probably intruded close together in time, but that the monzonite porphyry was intruded before quartz monzonite.[32] The present writer has confirmed this general relation. The monzonite porphyry usually occurs in sills and is cut by the quartz monzonite, which commonly occurs in stocks and dikes.

The intermediate type was not found cutting the monzonite porphyry, and the only basis for regarding it as somewhat younger is that in the normal sequence of differentiation calcic rocks precede silicic rocks. The coarsely porphyritic quartz monzonite cuts the intermediate type a short distance north of Bacon. The intermediate type has been mapped as a separate unit only in the southern part of the special area. It occurs elsewhere in the district, notably on Mount Guyot and at the mouth of Gibson Gulch in French Gulch, where its contact with the monzonite porphyry was so indistinct that it could not be mapped separately.

The association of monzonite porphyry with the "mineral belt" of Colorado has long been recognized.[33] From Leadville to Boulder the productive mines are confined to a narrow belt trending northeast, and the same belt includes nearly all the monzonitic porphyry in the region. There has been a growing tendency to recognize a genetic relationship between the quartz monzonite porphyry and the ore deposits of central Colorado.[34] The work of the writer in the Breckenridge and Montezuma districts has only served to confirm the theory that the ore deposits are the result of emanations from the deeper portions of the quartz monzonite magma.

The age of the monzonite porphyry is commonly given as late Cretaceous or early Tertiary [35] because dikes have been found cutting the Pierre shale and other sediments at the northeast end of the mineralized belt, near Boulder, in such association with folds as to suggest that the intrusion was contemporaneous with the major folding that formed the great foothill monocline [36] during the Laramide revolution. A large stock of quartz monzonite prophyry in the Montezuma district cuts a thrust fault that has brought pre-Cambrian gneiss above Pierre shale. As this fault is one of the major structural features of the west side of the Front Range and can be traced for 50 miles, it also is probably related to the Laramide revolution, which is commonly regarded as marking the transition from the Cretaceous to the Tertiary. The intense folding that occurred at this time involved the Denver and Middle Park formations on both sides of the Front Range but did not affect Oligocene sediments nor any unquestionable Eocene sediments. The Flattop peneplain, which was well developed before the end of the Eocene epoch, is distinctly later than the quartz monzonite prophyry stock referred to above. These facts indicate that the age of the quartz monzonite porphyry is Eocene.

[31] Ransome, F. L., op. cit., pp. 44, 50, 57.

[32] *Idem*, p. 71.

[33] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle, Colo.: U.S. Geol. Survey Prof. Paper 63, pp. 67–71, 1908.

[34] Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 381–388, 1924. Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U.S. Geol. Survey Prof. Paper 148, p. 209, 1927.

[35] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., p. 71.

[36] Fenneman, N. M., Geology of the Boulder district, Colo.: U.S. Geol. Survey Bull. 265, p. 40, 1905.

MONZONITE PORPHYRY.

The petrography of the igneous rocks of the Breckenridge district has been exhaustively studied by Ransome,[37] and the reader is referred to his report for detailed descriptions of the different varieties of porphyry. Only a summary of their general features will be given here.

Unaltered specimens of the monzonite porphyry are dark gray on fresh fracture. Nearly everywhere in the Breckenridge district where the rock is exposed at the surface it presents some shade of green owing to the development of secondary chlorite and epidote. The porphyritic texture is inconspicuous in the hand specimen, as few of the phenocrysts exceed 5 millimeters in length. Hornblende is usually the most conspicuous of the phenocrysts, but on some facies biotite is more abundant. The feldspar crystals are uniformly small and generally dull white.

Under the microscope biotite appears to be as common as hornblende, and both minerals are altered to chlorite, epidote, quartz, and calcite in varying degrees of completeness. Some augite is present and magnetite is common. The foregoing minerals are usually more or less intergrown with one another, whereas the plagioclase shows little tendency to form aggregates. The plagioclase ranges from a calcic andesine (Ab_1An_1) to a labradorite (Ab_2An_3). In the more calcic varieties of monzonite prophyry the orthoclase is confined to the groundmass, and in the less calcic varieties the orthoclase phenocrysts have no unusual features. In addition to orthoclase the groundmass contains abundant laths of plagioclase and minor amounts of quartz, biotite, augite, hypersthene, hornblende, magnetite, apatite, allanite, and zircon. The texture of the groundmass is usually holocrystalline.

The common alteration products of the feldspar are calcite, epidote, and sericite, and the ferromagnesian minerals are more or less changed to chlorite, epidote, quartz, and calcite.

Most of the porphyry in the special area is monzonite. It generally occurs as sills, some of which are very thick, and only in a few places was it observed to break across the bedding of the sediments which it invades. It is conspicuous on Nigger Hill, Gibson Hill, and Prospect Hill and in the valley of French Gulch and forms large masses in Mount Guyot and Bald Mountain, south of the special area. A dike of quartz monzonite porphyry cuts the older monzonite porphyry above the Wellington mine on Prospect Hill and establishes the age relations already indicated.

INTERMEDIATE TYPE

The intermediate type of porphyry is gray where fresh and grayish green where altered. Fresh material is more frequently observed in this type than in the monzonite porphyry. It usually has many phenocrysts of biotite, or locally of hornblende, from 3 to 5 millimeters in diameter. The gray plagioclase crystals are easily visible but are not conspicuous. The size and abundance of the quartz phenocrysts vary greatly; in many localities they can scarcely be detected in the hand specimen, but in others quartz is one of the most conspicuous phenocrystic minerals. Orthoclase is practically confined to the groundmass and was not observed to form phenocrysts in any locality. The presence of quartz phenocrysts distinguishes this porphyry from the monzonite porphyry, and the lack of conspicuous crystals of orthoclase makes it easy to separate from the quartz monzonite porphyry discussed in the next section.

Under the microscope the rock has the general appearance of the monzonite porphyry except in the character of the groundmass and the presence of corroded phenocrysts of quartz. The phenocrysts are andesine, biotite, hornblende, magnetite, and quartz. The groundmass is strikingly different from that typical of the monzonite porphyry; the network of minute plagioclase laths is absent, and in its place is a mosaic of fine-grained orthoclase and quartz, very similar to the groundmass of the coarsely porphyritic quartz monzonite described below.

QUARTZ MONZONITE PORPHYRY

The fresh quartz monzonite porphyry is generally light gray and weathers to buff or light-brown tints. The altered facies are usually of a much lighter shade of greenish gray than the monzonite porphyry altered under similar conditions. An outstanding feature of the quartz monzonite porphyry, and one of the best guides to its recognition in the field, is its conspicuously porphyritic appearance. Phenocrysts of orthoclase as much as 8 centimeters in length are common; quartz crystals as large as 1 centimeter in diameter and plagioclase laths as much as 1 centimeter in length are also abundant. Phenocrysts of hornblende are uncommon, and biotite is found only in moderate amounts as a megascopic constituent. The groundmass is generally very fine grained and presents a marked contrast to the large phenocrysts—a contrast that is lacking in the monzonite porphyry and enables the two rocks to be easily distinguished in the field.

Under the microscope the difference between the groundmass and the phenocrysts is accentuated and is much more striking than in the monzonite porphyry. The scattered phenocrysts of orthoclase are so large that they dwarf the other porphyritic constituents, but seldom does an orthoclase phenocryst appear in a thin section. The moderately large crystals of andesine-labradorite (Ab_1An_1) and corroded quartz are invariably conspicuous in the fine-grained mosaic of quartz and orthoclase that makes up the groundmass.

[37] Ransome, F. L., op. cit., pp. 43-62.

Some phenocrystic biotite is present in nearly all specimens, but hornblende is rare. The common accessory minerals include allanite, magnetite, titanite, zircon, and apatite. Alteration products are much less common than in the monzonite porphyry and include chiefly chlorite and calcite.

The quartz monzonite porphyry is abundant in French Gulch, near the northwestern boundary of the special area. It forms a small stock that has caused contact metamorphism in the limy shale of the Morrison formation nearby. Dikes of the coarsely porphyritic quartz monzonite cut monzonite porphyry on Prospect Hill and in Prospect Gulch, and the intermediate quartz monzonite porphyry is cut by the coarsely porphyritic quartz monzonite a short distance north of Bacon.

The late age of the porphyry is established by these relations, which are similar to those existing between these types of porphyry in other districts.[38] Ransome correlated the quartz monzonite porphyry of the Breckenridge district with the Lincoln porphyry of the Tenmile and Leadville districts because of their petrographic similarity, and the age relations a well as the form of occurrence of the two porphyries confirms this correlation.

ROCK ALTERATION

"CONTACT METAMORPHISM"

The larger masses of monzonite porphyry generally occur as thick sills, and this form of intrusion, here as elsewhere, rarely caused much change in the rocks which it invaded. Shale was locally indurated; limy shale assumed a greenish cast, probably caused by the development of small amounts of epidote; and the rocks near the contacts of the sill may have been shattered and show slight variations of color and hardness from that normal to them.

The stocklike masses of quartz monzonite porphyry, however, have caused marked alteration in many places. Contact-metamorphic minerals were noted at several localities by Ransome,[39] but only one of these is in the special area. The small stock in French Gulch, due east of Breckenridge, has had a marked effect on the calcareous beds near by. On Prospect Hill and Gibson Hill the limy shale beds of the Morrison have provided favorable horizons for the development of garnet, epidote, dark-green amphibole, quartz, specularite, magnetite, and small amounts of pyrite and chalcopyrite. Close to the quartz monzonite porphyry the garnet and epidote are the most conspicuous minerals in the limy beds, but the garnetization was generally limited to the formations within 1,500 feet of the stock, whereas epidote and quartz replaced favorable beds at much greater distances. The other contact minerals mentioned are locally abundant but are sparingly developed in general.

[38] Crawford, R. D., op. cit., pp. 377, 378.
[39] Ransome, F. L., op. cit., pp. 93–94.

Metamorphism is shown only on the north side of French Gulch, where garnetized shale crops out from the Wellington mine to the western slope of Gibson Gulch, a distance of about a mile. The apparent lack of metamorphism on the south side of French Gulch may simply reflect the absence of favorable horizons at the surface, and it is possible that the calcareous beds that underlie the Dakota quartzite in this region have undergone changes similar to those which they show on the north side of the valley.

The development of "contact-metamorphic" minerals is thought to result from the action of hot magmatic fluids given off from the deeper portions of the slowly cooling quartz monzonite mass. As Ransome[40] pointed out, there is probably no sharp line of demarcation between these solutions and those that deposited the sulphide ores of the district. The rarity of hematite and the presence of sulphides in the metamorphic aggregates indicate that the solutions were probably reducing in character shortly after the early stage, when "contact" silicates were formed. This character is reflected in the alteration of the different formations.

HYDROTHERMAL ALTERATION

Ransome[41] made a thorough study of the alteration of the porphyry wall rocks of the veins, and the reader is referred to his report for detailed consideration of this subject. The following summary of the changes in the rocks near the veins gives the results of Ransome's work supplemented to a small degree by the writer's observations.

The bright-red sediments of the Maroon formation were changed to green or gray in zones of contact-metamorphic action or near ore channels, and a similar change was noted in the red shale of the Morrison formation. This change in color resulted from the reduction of the oxidized iron in the red beds to a ferrous state. The black shale of the various formations generally remains black even where the beds have been completely silicified. The addition of pyrite to the red sediments was invariably attended by a bleaching of the color, but weathering of pyritized rocks resulted in the oxidation of the iron, and under these conditions the rock became reddish brown at the surface, regardless of its original color. The warm reddish brown of the weathered Pierre shale on Mount Guyot, west of Georgia Pass, is due to the oxidation of finely disseminated pyrite.

In regions where hydrothermal alteration was intense the arkosic grit of the Maroon formation was altered to dense aggregates of quartz, chlorite, ankerite, pyrite, and sericite, but in the shale of this formation the chief effects of the ore-bearing solutions were the bleaching of the color and the development of chlorite, pyrite, and chalcedonic quartz. Where calcareous

[40] Ransome, F. L., op. cit., p. 93.
[41] Idem, pp. 94–102.

beds formed the walls of veins they were usually silicified and replaced by pyrite and to a less extent by other sulphides.

The dark Cretaceous shales have been almost completely converted into jaspery silica near some of the larger veins of the district. This dense black silica is similar to the "flint" or jasperoid of the Leadville district in its occurrence.[42] It is in part associated with ore channels but occurs as abundantly in the barren parts of a vein as it does near ore shoots.

In many places near veins the monzonite porphyry and the quartz monzonite porphyry were almost completely altered to sericite, quartz, and ankerite with minor amounts of pyrite. Commonly as a vein is approached ankerite increases, and sericite at first increases rapidly and then decreases, but quartz increases steadily, although owing to the replacement of the original silicates by ankerite and sericite the total silica content decreases, as is illustrated by a series of specimens collected by Ransome, grading from fresh, unaltered monzonite porphyry 26 feet from the Wellington vein to the completely altered wall rock 6 inches from the vein. During its alteration the monzonite porphyry lost approximately 19 percent of its silica, 22 percent of its alumina, all of its ferric iron, 73 percent of its calcium oxide, 70 percent of its sodium oxide, and 50 percent of its potassium oxide, and gained 260 percent in ferrous iron, 165 percent in magnesia, 485 percent in water, 2,500 percent in carbon dioxide, whereas titanium and phosphorus showed little change. Small amounts of pyrite (2 percent), sphalerite (1 percent), and galena (0.5 percent) were introduced.

Near some of the gold veins in the quartz monzonite porphyry the rocks have been strongly silicified and sericitized, pyrite is abundant, and no ankerite or other carbonate is present. Near the Jessie mine the quartz monzonite had apparently lost all its ferrous and ferric oxide, carbon dioxide, and magnesia, almost all of its calcium oxide, and 87 percent of its sodium oxide and had gained about 770 percent of pyrite (from 0.09 to 9.92 percent), 300 percent of water, 18 percent of potassium oxide, and 3 percent of silica; alumina, titanium, and phosphorus showed little change. Small amounts of lead, zinc, and copper sulphides were introduced. The analyses on which these figures are based show the effects of moving solutions whose composition was constantly changing. The different types of rock alteration may be explained by assuming either that they were typical of different distances from the magmatic source of the solutions or that they resulted from magmatic solutions whose initial compositions were different. In general, sericitization has been the dominant type of rock alteration in the Breckenridge district and was commonly accompanied by the formation of ankerite. Silicification has been extensive in many places and commonly represented alteration at a higher temperature than the sericitization.

Another kind of rock alteration, and the one that has been most widespread in the district, is ascribed by Ransome to the action of solutions rich in carbon dioxide that were derived from the zone of weathering but were active well below the level of ground water. In all the specimens of monzonite porphyry collected from surface exposures the ferromagnesian minerals were altered chiefly to chlorite and to a lesser degree to calcite and epidote, and the feldspars generally contained some calcite, sericite, and kaolinite. Some pyrite and secondary quartz are also common. The alteration of the ferromagnesian minerals to chlorite is typical of the rock alteration called propylitization and is usually associated with the milder phases of hydrothermal action accompanying ore deposition. However, Ransome states that the propylitized rocks are restricted to a zone within 300 feet of the surface and that this type of rock alteration shows no relation to the channels of mineralization. The writer is unable to add new data on this subject. The relation of the propylitized rock to the surface must be more than accidental, but the development of sericite and epidote indicates the action of hot solutions, and it is worthy of note that the later porphyry is less propylitized than the monzonite porphyry.

STRUCTURE

Regional features.—The structure of the Breckenridge district is only a small detail of the structure of a much larger region that embraces all the mountainous part of Colorado and continues into Wyoming and New Mexico. The outstanding features of the region surrounding Breckenridge have been described elsewhere by the writer[43] and will only be briefly reviewed here.

The sediments of the Breckenridge district lie in a structural trough about 10 miles wide that extends north-northwestward from South Park to Middle Park. The belt of sediments is about 8 miles wide and is flanked by pre-Cambrian rocks on the east and west. The older formations in South Park, such as the Cambrian, Ordovician, Devonian, and Carboniferous, thin rapidly to the north and disappear successively, allowing younger and younger sediments to rest on the pre-Cambrian floor. This progressive overlap is of economic importance, as it has resulted in the absence from the Breckenridge district of the Ordovician and Leadville limestones, noteworthy ore-bearing beds in Leadville, Aspen, and other mining districts of central Colorado.

Owing to isoclinal folding, the regional dip is eastward throughout the structural trough. The oldest formations rest on the pre-Cambrian rocks of the Tenmile and Gore Mountains and pass eastward under an

[42] Emmons, S. F., Irving, J. D., and Loughlin, G. F., op. cit., pp. 217–218.

[43] Lovering, T. S., Geologic history of the Front Range, Colorado: Colorado Sci. Soc. Proc., vol. 12, no. 4, pp. 59–111, 1929.

ever increasing thickness of sediments until folded and faulted back on themselves at the western edge of the Front Range. About 5 miles east of Breckenridge, the sediments are limited by an overturned fold, which passes northward into a thrust fault of large magnitude. The overturned fold is well shown a short distance southwest of Georgia Pass, where the contact of the Dakota quartzite and the overlying pre-Cambrian gneiss dips 65°–70° E. This fold passes northward, about a mile north of Tiger, into the Williams Range thrust fault,[44] which the writer has interpreted as an underthrust. From this locality to the Lower Muddy Butte, a few miles north of Kremmling, the Cretaceous shales are thrust eastward under the pre-Cambrian rocks. Near Keystone there is a known horizontal movement of 4 miles, and the Cretaceous shales may continue their eastward dip under the pre-Cambrian rocks for some distance farther.

The Mosquito fault forms the western boundary of the tetonic block that is limited on the east by the Williams Range thrust fault and the overturned fold and is regarded as a structural unit. The Mosquito fault extends from Leadville to the Tenmile district, and according to Emmons,[45] it probably continued 25 miles to the northwest of the west fork of Tenmile Creek. It is a normal fault near Leadville, but the fault plane steepens as it is followed to the north, and in the Tenmile district it overturns and becomes a reverse or thrust fault. Where it is a thrust fault, the pre-Cambrian rocks overlie the Maroon formation, just as they overlie the Cretaceous shales along the Williams Range thrust fault 10 miles to the east.

The trough of the overturned synclinal fold must have been a weakened zone, especially favorable for intrusive activity. From South Park to the region north of Tiger, where the overturned fold gives way to the Williams Range thrust fault, the axis of the fold is marked by an almost continuous series of large porphyry masses. Much of this porphyry occurs as large sills of monzonite and diorite porphyry, but stocks of quartz monzonite porphyry are also present. The intrusion of the porphyry into the strongly folded sediments was preceded and accompanied by faulting, and most of the faults and nearly all the porphyry masses occur in the eastern half of the tectonic block outlined above. These faults and porphyry masses form the westernmost part of a transverse zone of fissuring and subsequent ore deposition that extends from Breckenridge to Boulder. This zone is more conveniently described and interpreted on pages 20–21.

Local features.—In the region north of the Breckenridge district, where exposures are better, studies by the writer have resulted in a better understanding of the details of the geologic section and the general structure than is possible from work confined to the district. Much helpful information, which was also unavailable to Ransome, has been gained in the lower levels of the Wellington and Golddust mines and in a study of the bedrock fragments on the dredge piles. The interpretation of local structure which follows thus differs in many respects from that in Professional Paper 75. The overturned asymmetric regional syncline broken by the underthrust fault in the northeastern part of the district, the closely compressed syncline north of Rocky Point, and many details of the fault pattern and of the distribution of the sediments, shown by the writer, were not recognized during Ransome's work in the district.

The special area in the Breckenridge district is on the western limb of the regional syncline about 2 miles west of its axis. As shown on the geologic map (pl. 2) and the cross sections (pl. 5), both open and moderately close minor folds and crumplings, which are present at places on both limbs of the regional fold, are well defined in the special area. The larger elements of structure in the special area are moderately simple and should be pictured before their features are considered in detail. In the southwestern part the prevailing northeasterly dip of the region is interrupted by an anticline and syncline, both of which trend northwest. Two broken, down-faulted belts cross these folds and intersect near the central part of the special area. One of the belts trends north-northeast and the other east-northeast.

A compressed syncline extends northwest from Bacon to a point about 500 feet south of Little Mountain. Both limbs dip toward the axis at about 60°, and formations from the Pierre to the Maroon are uniformly exposed on the southwestern limb. The northeast side of the fold passes into a gentle anticline, with northwest pitch, which extends northwestward from the head of Illinois Gulch through Nigger Hill to Breckenridge. This anticline is broken by cross faults and is the site of large porphyry intrusions. As a result the formations on each side of the anticlinal axis are markedly discontinuous and contrast with the uniform linear belts of sediments to the southwest. North and northeast of this anticline the formations have a general dip of 20°–30° NE., conforming to the regional structure, as shown in section A (pl. 5). There is evidence of gentle doming on Gibson Hill, but even here the prevailing dips are toward the east or northeast.

All of the area northeast of the compressed syncline is so complexly faulted and so broken by monzonite porphyry sills and cross-cutting masses of quartz monzonite porphyry that the structure is none too clear on the map; neither does the detail of the intricate faulting lend itself to clear description, but, as noted above, the major features can easily be pictured.

[44] Lovering, T. S., Williams thrust fault: Geol. Soc. America Bull., vol. 39, p. 173, 1928; Field evidence to distinguish overthrusting from underthrusting: Jour. Geology, vol. 40, pp. 660–663, 1932.

[45] Emmons, S. M., U.S. Geol. Survey Geol. Atlas, Tenmile district folio (no. 48), p. 3, 1898.

The southern part of the north-northeasterly belt of faults is bounded on the west by the strong fault that trends north-northeastward through the saddle on Little Mountain, across Illinois Gulch, and through the saddle 1,000 feet east of the United States locating monument on Nigger Hill. This fault marks the western limit of the large masses of monzonite porphyry that extend from Nigger Hill southeast to Bald Mountain.[40] This fault has a vertical displacement of about 350 feet at Little Mountain and about 750 feet on the south side of Nigger Hill, but this decided increase in throw is probably due to the presence of a branch fault striking nearly east in Illinois Gulch. The east side of the major fault has dropped, so that porphyry and Cretaceous shale on the east are brought against Morrison on the west. On the north side of Nigger Hill the displacement is distributed on several faults striking northeast, and the zone of movement is stepped eastward as it is followed to the north.

The dropped belt east of this fault zone continues across French Gulch, where it is limited on the west by the Bullhide fault, which extends up the small gully about 200 feet west of the Wellington mill. In this locality the displacement is hard to calculate because of the many branching faults that are present. The Pierre shale is faulted against the Morrison formation near the Wellington mill, and a vertical movement of about 800 feet is indicated. At 800 feet north of the mill a quartz monzonite porphyry dike is offset 300 feet along the Bullhide fault. Underground work shows that the Bullhide fault dips about 58° E. and is therefore a normal fault. If the dike is vertical the displacement indicates that the western wall of the fault moved 300 feet south, but if the porphyry dike dips to the south the apparent lateral movement may represent the normal offset caused by a fault with a large vertical displacement and a small horizontal component.

South of French Gulch the east side of the north-northeasterly belt of dropped ground is raised gradually along a series of north-northeast faults of comparatively small throw. As the Nigger Hill anticline plunges northwest, older and older rocks rise to the surface southeastward along the fold. This upward trend of the formations is accelerated by the step faulting along the eastern border of the downthrown belt. Most of the faults of this series whose dips are known are normal.

The other down-faulted grabenlike belt extends east and northeast from Breckenridge, crossing and accentuating the central part of the north-northeastward trending dropped belt described above. The northern limit of this second down-faulted belt runs nearly due east from Breckenridge across French Gulch and turns northeast into Prospect Hill at the Wellington mill. In Prospect Hill the Wellington vein is in the chief fault on the north side of the depressed belt. This fault is normal, dips about 63° SE., and has a dip slip of about 110 feet.

The south limit of this belt extends eastward from the north side of Little Mountain across Illinois Gulch and enters Nigger Hill near the Golddust shaft. Beyond this place it turns gradually to the northeast and appears on the southeast side of French Gulch near the mouth of Australia Gulch. The Golddust vein and the Country Boy veins are the best-known veins on fault fissures along the southern border of this downthrown belt. The Country Boy vein is in a normal fault, but the Golddust vein is in a steep reverse fault. This complexly faulted belt is limited on the north and south by discontinuous faults. In some places the movement is taken up by a series of step faults, in other places a single fault will absorb all the movement, and in still other places a zone of shattered rock or a wide sheeted zone marks the edge of the belt.

Very few faults that trend northwest were found, and the relative ages of those within the special area could not be determined, but in the surrounding region most of the northwesterly faults are older than those that trend north and northeast. The faults that strike N. 40°–80° E. are by far the most common in the Breckenridge district. They are generally older than those that strike N. 10° W. to N. 20° E. The latter fault system includes most of the normal faults with large displacement, and much of the movement along them was later than ore deposition. Nearly all the veins in the district are found in fault fissures of the east-northeast system. On Gibson Hill, however, many of the "blanket veins" occur in replaceable beds of different formations and along gently dipping bedding-plane "slips."

Most of the monzonite in the special area is part of one large irregular laccolithic mass that formerly extended in a continuous sheet from Prospect Hill south to Nigger Hill and southeast to Bald Mountain. This mass was fed by many conduits and is probably composed of many distinct sills that have united to form the larger body. The base of the large intrusive sheet is irregular and follows different horizons in different places but most commonly occurs a short distance above or below the Dakota. The bulk of the porphyry was intruded after folding was completed, and part of it is later than the initial east-northeast faults (see description of Wellington mine, p. 48), but many of the faults in the district are later than the monzonite porphyry. It is probable that the large sheet was broken by the fault that bounds it on Nigger Hill and that its northwestern extension has been removed by erosion. Structure sections H, I, and J (pl. 5), show what is known of the base of the monzonite mass.

In general, the crosscutting bodies of monzonite and quartz monzonite porphyry followed the earlier

[40] Ransome, F. L., op. cit., pl. 1.

lines of weakness indicated by the east-northeast faults, but in a few places the porphyries broke across the sediments in a north-south line. This feature is illustrated on the eastern edge of the quartz monzonite porphyry stock south of Gibson Hill, and in the cross-breaking mass of monzonite porphyry north of it. As most of the north-south fractures are distinctly later than the east-northeast fractures and in places offset quartz monzonite dikes, it is probable that lines of weakness were just beginning to develop in the northerly directions as the intrusive activity was drawing to an end.

Some local faulting accompanied and resulted from the intrusion of the porphyries. The faults along the north side of Nigger Hill may be related to the intrusion of the quartz monzonite stock north of them. In many places the intrusion of sill-like branches from dikes that followed preexisting fault planes has either accentuated or diminished the original throw of the fault above the sill; a fault may be normal below a sill, but above the sill its hanging wall may have been so much raised by the intruding porphyry that it now has a reverse appearance.

Relation to Front Range mineral belt.—The detailed study of the special area of the Breckenridge district shows a complicated fault mosaic whose genesis is clouded with detail. Knowledge of the regional geology, however, makes it clear that this badly broken ground is the natural result of the forces involved in the diastrophic movements that formed the Front Range of the Rocky Mountains. The earliest record of these movements is contained in the overturned fold that passes northward into the Williams Range underthrust fault. The general trend of the fault, N. 30° W., indicates a compressive force operating in a direction approximately S. 60° W. or N. 60° E. Compression in this direction has been recognized in the Leadville district also, where Loughlin [47] concluded that a compressive force must have acted S. 60° W., because the folds that trend N. 30° W. have steep western limbs and several of these limbs are broken by reverse faults.

Little evidence has been found that regional compressive forces acted at any later time in directions other than west-southwest or east-northeast. The forces involved in the thrusting were of large magnitude and accumulated so rapidly during the Laramide revolution that rock flowage was unable to keep pace with the increasing stresses, and fracturing resulted. The first fractures near Breckenridge followed the line of the great overturned fold of the region and developed into the Williams Range thrust fault, north of Tiger. This fault passes into the overturned fold south of Tiger, where compression was evidently less severe than it was in the region farther north, near Keystone. A few miles east of Keystone, at the junction of the North Fork and South Fork of the Snake River, Pierre shale is exposed in a "window" which has been eroded through the overlying pre-Cambrian rocks. This shale is several miles east-northeast of a line passing through and paralleling the overturned sedimentary contact of the Dakota quartzite with the pre-Cambrian gneisses at Georgia Pass, 4½ miles south-southeast of Tiger. This relative position shows that the shale north of Tiger was thrust much farther eastward under the rising pre-Cambrian rocks than the shale south of the town. Although the regional geology shows that compressive, mountain-building forces were acting in an east-northeast or west-southwest direction over a wide area, it is evident that locally the forces differed greatly in intensity. Thus the underthrust of the sediments near Tiger, several miles east of the corresponding beds south of the town, indicates a strong regional shearing force in an east-northeast or west-southwest direction.

The compressive and shearing forces that caused the unsymmetrical infolding and underthrusting of the Cretaceous sediments near Tiger had little effect on the large batholithic masses of granite in the Front Range, but they greatly affected a northeasterly zone of incompetent schist and gneiss between strong granite buttresses. In this belt, which follows a sinuous course from Tiger northeast to Boulder, shear faults are common, and in nearly all these faults the north wall has moved eastward past the south wall. Intrusive activity as well as fracturing was concentrated in this irregular, incompetent zone, and emanations from the deeper parts of the intrusive magma later formed many ore deposits in or near the intrusive masses now exposed. Compression was locally relieved by interlaminal movement in the soft schists, but the stronger ribs of granite and granite gneiss either transmitted the force without rupturing or absorbed some of the force by fracturing. These fractures later provided channels of circulation for ore solutions and thus helped to localize mineralization. The restriction of Tertiary intrusive masses and veins to the incompetent zone has caused this strip of country to become known as the "porphyry belt" or the "mineral belt." [48] This belt is about 6 miles wide where it comes to the western edge of the pre-Cambrian mass 5 miles east of Breckenridge but is narrower a few miles to the northeast.

North of Tiger the compressive forces found relief through movement along the Williams Range thrust fault, and it is probable that little faulting transverse to the thrust fault occurred in the sediments. Peripheral faults related to the subsequent intrusion of a northward-trending quartz monzonite stock are common, however. In the region south of Tiger, where the underthrust passes into an overturned fold, transverse shearing and compressive faulting were at a

[47] Emmons, S. F., Irving, J. D., and Loughlin, G. F., op. cit., p. 96.

[48] Lovering, T. S., Localization of ore in the schists and gneisses of the mineral belt of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, pp. 237-242, 1930.

maximum in both the sediments and the pre-Cambrian rocks. As a result the sediments are much less fractured north and south of the mineral belt. Southwest of the pre-Cambrian rocks, in line with the mineral belt, the stresses that existed were, in effect, (1) compression from the west-southwest, (2) shearing directed to the east-northeast, and (3) tension or only slight compression in a north-northwesterly direction. The fracturing that would result from such a combination of stresses would have the most open fissures parallel to the direction of major compression and at right angles to the direction of tension. The fractures caused largely by compression would make angles of less than 45° to the direction of compression; steeply dipping compression fractures in this region should therefore trend east or slightly east of north.[49]

Although the fractures and faults in the district were largely caused by the same forces and in a broad way belong to one period of fracturing, they are not strictly contemporaneous. Experimental work with bodies compressed under differences in stress analogous to those described above show that the shear cracks and open tension cracks form parallel to the direction of compression and are commonly a little earlier than the compression cracks. The compression fissures form in two sets at angles of less than 45° to the direction of compression, and these two sets may develop simultaneously, but more commonly one set develops before the other. Each of these three stages—compression, shearing, and tension—increases to a maximum and then wanes, but there is an overlap of one stage on another. Further relief from compression is obtained by the shoving and rotation of the blocks into which the mass has thus been broken. The faults in the Breckenridge district are largely the response of interbedded competent and incompetent rocks to these compressive and shearing forces localized along a 6-mile front, but the pressure of large irregular masses of porphyry caused many local variations in the courses of the fractures. There is no sharp distinction in age between the different fault systems of the district, and they are in part contemporaneous, the later faulting of one stage having overlapped the earlier faulting of another. Movement on many of the faults recurred at intervals over long periods of time, and it is probable that the stress that caused the last faults also caused some readjustment on the existing fault planes.

The veins of the district occupy those older faults that served as good channels of circulation for the metallizing fluids from the deeper parts of the quartz monzonite magma. As the solutions followed the easiest avenues of escape, the ores are largely confined to the more open of the older faults. As suggested above, such faults commonly trend northeast or east-northeast. Some of the strong northerly fractures were also mineralized, but as they were comparatively tight no deposits of commercial size were formed in them. Their relation to important veins suggests that some of these slightly mineralized faults may have been deep-reaching channels of mineralization. Such relations are illustrated by the occurrence of ore at the Wellington mine. (See pp. 26, 27, 50, 51.)

GEOLOGIC HISTORY

The geologic history of the Breckenridge district is only partly recorded in the formations that are now exposed here. Many details that are of interest in presenting a general picture of the geologic past must be gathered in regions remote from this district. The summary given below brings together the features of the geologic history necessary to an understanding of the district. It is based largely on the writer's study of the Front Range from 1926 to 1929, and the evidence for the statements made has been presented elsewhere[50] and will not be repeated here.

During pre-Cambrian time thick shaly sediments were deposited on an unknown basement, folded and metamorphosed into schists, intruded by large masses of granite, raised into mountains, and worn down to nearly featureless plains on both sides of an area of slightly higher land that existed along the site of the present Front Range. This highland was separated by a broad basin from a similar high area stretching northwest and southeast of the present town of Creede. The Cambrian sea spread over the pre-Cambrian lowlands and may have covered the Breckenridge district. At the end of the Cambrian period gentle but widespread uplift caused the sea to withdraw.

Oscillations of the earth's surface resulted in successive invasions and withdrawals of the sea in the Ordovician, Devonian, and Carboniferous periods. The areas occupied by the sea in each period were much the same, but in general each marine invasion was a little more widespread than the one before.

There is little in the character of the Cambrian, Ordovician, Devonian, and Mississippian sediments to indicate proximity to a rugged land surface, but there is clear evidence of the rejuvenation of erosive agents in the Pennsylvanian epoch. Thick beds of conglomerate, cross-bedded sandstone, micaceous shale, and grit all testify to the activity of erosion in nearby land areas, and the presence of coarse boulder conglomerate interbedded with fine grit and shale indicates that the earlier mild climates had given way to one in which violent fluctuations were common. This change was evidently in the direction of increasing aridity, as carbonaceous shale is absent in the upper part of the Pennsylvanian series, and the increasing prominence

[49] Lovering, T. S., The fracturing of incompetent beds: Jour. Geology, vol. 36, pp. 709-717, 1928.

[50] Lovering T. S., Geologic history of the Front Range, Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 59-111, 1929; Localization of ore in the schists and gneisses of the mineral belt of the Front Range, Colorado: Idem, pp. 234-268, 1930. Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 92-93. Ransome, F. L., op. cit., pp. 182-183.

of red micaceous sediments in the upper part of the section also suggests semiarid conditions. The eastern shore line of the Pennsylvanian sea passed through the Breckenridge district, and it is probable that in the succeeding epoch Permian sediments lapped over the pre-Cambrian rocks for several miles eastward. Probably erosion was mildly active in this region from the end of the Permian epoch to the beginning of Cretaceous time. The geologic record of the Triassic period is difficult to interpret, but it is probable that arid conditions prevailed and that sedimentation was insignificant.

The Jurassic period saw a return to a more humid climate as shown by the fresh-water sediments of the Morrison (Upper Jurassic) and the lack of rugged country nearby is indicated by the character of the shale and sandstone in that formation. The lack of relief in the Jurassic land areas suggests the old-age topography of a sinking land mass.

The highlands of Paleozoic and early Mesozoic time slowly sank below the level of the Cretaceous sea until, at the end of Dakota time, only a few islands marked the high points of the ancestral Front Range. The humid climate of Dakota time is recorded in the many seams of coaly shale near Breckenridge and in similar beds of carbonaceous shale interbedded with fire clay elsewhere. During Benton and Niobrara time and the first half of Pierre time subsidence continued and probably resulted in the complete submergence of the Front Range highland to a moderate depth. In the later half of Pierre time, however, this ancient highland slowly emerged and was again laid bare to the attack of erosion. The emerging highland gradually pushed the shore of the receding ocean farther and farther out, and this shoaling of the sea is recorded in the alternations of the marine and continental beds in the equivalents of the upper part of the Pierre and of the Fox Hills formation. The emergence of the land was not accompanied by folding but seemed to be the result of a vertical uplift that raised most of North America above the ocean. Although pronounced folding did not occur until the end of the Denver epoch, it is certain that the Front Range highland was elevated well above the level of the plains at the end of Laramie time. It is probable that this elevation was caused by a gentle doming of the area now occupied by the Front Range and was accompanied by the pronounced volcanic activity that is believed to have covered the Front Range with lavas during Denver time. The doming was a forerunner of the violent mountain-forming movement called the Laramide revolution that marked the transition from the Cretaceous period to the Tertiary period. This widespread diastrophism, which in large measure built the Rocky Mountain system, occurred at the end of this very early Eocene stage, when the Denver and all the older formations were strongly folded, in places overturned, and faulted on a large scale where compression was greatest. The Williams Range thrust fault and the related shear and tension faults were formed during the Laramide revolution, and it is probable that the reverse faults on the east side of the Front Range, near Golden and Boulder, were also formed then. Shortly after the beginning of the stage of shear faulting, sills of diorite and monzonite were intruded in the Breckenridge district, and intermittent intrusion of increasingly silicic rock continued throughout the Laramide revolution, culminating after the thrust faulting in the emplacement of large stocks of coarsely porphyritic quartz monzonite. Minor faulting accompanied and followed their emplacement but waned rapidly during the ensuing stage of ore deposition.

The folding and faulting must have raised the tops of the resulting mountains to high altitudes and early Tertiary time probably found the ancient highland elevated to a lofty mountain range containing many active volcanoes. The rejuvenation of the streams that accompanied the great mountain uplift caused rapid erosion. The volcanic rocks that covered the pre-Cambrian core of the Front Range were cut through and removed over large areas. Before the end of Eocene time erosion had reduced the rugged surface to a gently undulating upland plain, above which rose a few monadnocks of andesite and granite. It is probable that some of the conspicuously even surfaces of this plain, now called the Flattop peneplain, were remnants of the earlier erosion surface over which the Cretaceous sea advanced at the beginning of Dakota time and which were uncovered in late Cretaceous and early Eocene time.

Very early in the Eocene epoch, before the cover had been completely stripped from the pre-Cambrian core of the Front Range highland, a series of monzonitic sills, dikes, and stocks were intruded in the region now known as the mineral belt of Colorado. The emanations from these porphyry masses formed many metalliferous veins throughout this belt and were the source of the ores of the Breckenridge district. The ores were formed under a moderately thick cover, and it is probable that they did not come within reach of ground water until erosion had decreased greatly from its early Eocene activity. From this time on, however, the ore deposits were slowly reconcentrated and enriched through the action of meteoric waters. The climate and the activity of erosion are determinative factors in enrichment, and thus the climatic as well as the geologic history of the Tertiary and Quaternary periods is worthy of consideration.

During the Eocene epoch a mild and moderately humid climate prevailed in the lowlands bordering the newly formed mountains. A lush vegetation flourished in the plains and basins, and though there is no record of the fact, the mountains themselves were undoubtedly forest-clad throughout this epoch.

There is evidence of uplift at the end of the Eocene and the consequent rejuvenation of erosive agents. Faulting probably accompanied the uplift.

The Oligocene epoch was characterized by a continuance of the mild Eocene climate, but the rainfall was distinctly less than that of the Eocene. Although some uplift occurred in middle and late Oligocene time, the epoch saw no marked rejuvenation of the streams.

The Miocene climate was mild but drier than that of the earlier Tertiary epochs. Volcanic activity and pronounced uplift in lower and upper Miocene time are recorded in the Front Range, and it is probable that intermittent volcanic activity continued from the beginning to the end of this epoch in the Cripple Creek region and in Middle Park. The Miocene plains deposits contain hackberry fruits, indicative of a semiarid environment, but the Florissant lake beds contain a diversified flora and fauna, indicating that the Miocene mountains were covered with abundant vegetation. The activity of erosion that was begun by the Miocene uplift caused rapid degradation of the mountain fronts, as it was there that the change in the gradient of the streams was most effective. During Miocene and Pliocene time an uneven compound erosion surface, known as the Rocky Mountain peneplain, was carved on the eastern flank of the Front Range. This surface is not so well developed in the pre-Cambrian rocks on the west side of the Front Range, but remnants of the older Flattop peneplain are conspicuous there. The pronounced physical differences of the Cretaceous shale and the Tertiary monzonite porphyry in the Breckenridge district greatly influenced the development of topographic form after the Miocene uplift and resulted in a moderately accented surface instead of a piedmont plain.

The early and middle Pliocene were characterized by a return of mild and humid conditions throughout most of North America. There is some evidence of widespread and severely arid conditions in upper Pliocene time, but most of our information on the late Pliocene is obtained by extrapolation from the conditions known to have prevailed at the beginning of Pleistocene time. There can be no doubt, however, that the upper Pliocene was decidedly more arid than the earlier Tertiary epochs. This period of extreme aridity was ideal for the enrichment of lead, silver, and gold, and there must have been a notable concentration of these metals in the upper parts of the veins at this time.

The Front Range was raised into a broad arch at the beginning of the Quaternary period, and it is probable that some of the postmineral faulting exhibited in the Breckenridge ore deposits occurred at this time. This uplift or the coincident change to a humid climate brought about the period of vigorous erosion that has lasted to the present time. Two epochs of notable glaciation followed the uplift, separated by a long interval during which some streams cut channels as much as 160 feet deep in bedrock. It is unlikely that a great amount of enrichment occurred in the veins in glacial time, but the streams were vigorously and effectively concentrating gold in the placers that have supplied most of the gold output of Summit County.

MINERALOGY

Ransome[51] has described most of the minerals occurring in the Breckenridge district, and the reader is referred to his paper for such details as are not included in the tabular summary shown below. The writer has added a few minerals to the list given by Ransome, but it would be unprofitable to take space for a detailed description of these additions. The composition and genesis of every mineral is indicated in a general way in the table, but the relations of the common ore minerals are considered more fully below, and further information regarding them can be found in the descriptions of the individual mines.

Pyrite is the earliest of the common sulphides. Marmatite (dark, ferruginous zinc blende) containing minute blebs and stringers of chalcopyrite, followed the pyrite; it is usually earlier than galena, but in some ores it is contemporaneous with galena and locally it is later. (See pl. 7, *A*.) Most of the light-colored zinc blende is later than galena. Gold and a small amount of the blende are contemporaneous with the last stage of galena formation. Quartz and ankerite followed the deposition of the sulphides in most places, but the gangue minerals form only a small portion of the ore in most veins in the district.

[51] Ransome, F. L., op. cit., pp. 81-91.

Minerals of Breckenridge district, Colorado

Name and composition	Hypogene				Supergene	
	In igneous rocks	In contact-metamorphic deposits	In high-temperature deposits	In moderate-temperature deposits	In secondary sulphide zone	In oxidized zone
Allanite, $Ca_2(Al.OH)(Al,Fe,Ce,La,Di)_2(SiO_4)_3$	×					
Amphibole, $CaMg_3(SiO_3)_4$	×					
Andesine, Ab_7An_3	×					
Ankerite, $(Ca,Mg,Fe)CO_3$		×		×		
Apatite, $(Ca,F)Ca_4P_3O_{12}$	×					
Augite, $CaMgSi_2O_6$, with $(Mg,Fe)(Al,Fe)O_2Si_6$	×					
Azurite, $2CuCO_3.Cu(OH)_2$						×
Barite, $BaSO_4$					×	
Biotite, $(H,K)_2(Mg,Fe)_2Al_2Si_3O_{12}$	×					
Bismuthinite, Bi_2S_3				×		
Calcite, $CaCO_3$				×		×
Cerusite, $PbCO_3$						×
Chalcedony, SiO_2				×	×	×
Chalcocite, Cu_2S				×	×	
Chalcopyrite, $CuFeS_2$		×		×		
Chlorite				×		
Chrysocolla, $CuSiO_3.2H_2O$						×
Clay					×	×
Copper, Cu						×
Diopside, $CaMg(SiO_3)_2$		×				
Dolomite, $CaMg(CO_3)_2$				×		
Epidote, $H_2O.4CaO.3(Al,Fe)_2O_3.6SiO_2$		×	×	×		
Ferric sulphate, basic, $Fe_2O_3.SO_3.2H_2O$						×
Freibergite, $4(Cu_2S,Ag_2S)_3.Sb_2S$				×		
Galena, PbS			×	×	?	
Garnet, $R''_3R'''_2(SiO_4)_3$ or $3RO.R_2O_3.3SiO_2$, when R'' equals Ca,Mg,Fe, Mn and R''' equals Al,Fe,(Mn),Cr,Ti		×				
Gold, Au		×	×	×	×	×
Gray copper, $Cu_8Sb_2S_7$ or $4Cu_2S.Sb_2S_3$				×		
Gypsum, $CaSO_4.2H_2O$					×	×
Hematite, Fe_2O_3		×	×			
Hornblende, $Ca(Mg,Fe)_2(SiO_3)_3$	×					
Hypersthene, $(Mg,Fe)SiO_3$	×					
Jarosite, $K_2O.3Fe_2O.4SO_3.6H_2O$					×	×
Kaolin, $2H_2O.Al_2O_3.2SiO_2$					×	×
Labradorite, AbAn	×					
"Limonite," $2Fe_2O_3.3H_2O$						×
Magnetite, Fe_3O_4	×	×				
Malachite, $CuCO_3.Cu(OH)_2$						×
Manganosiderite, $(Fe,Mn,Mg)CO_3$				×		
Marmatite, $(Zn_3Fe)S$			×	×		
Melanterite, $FeSO_4.7H_2O$						×
Microcline, $KAlSi_3O_8$	×					
Muscovite, $KH_2.Al_3(SiO_4)_3$	×					
Oligoclase, Ab_6An_1	×					
Orthoclase, $KAlSi_3O_8$	×					
Plagioclase, $x(NaAlSi_3O_8)y(CaAl_2Si_2O_8)$	×					
Psilomelane, H_4MnO_5						×
Pyrite, FeS_2		×	×	×	×	
Pyrolusite, MnO_2						×
Quartz, SiO_2	×	×	×	×		
Rutile, TiO_2	×					
Sericite, $KH_2Al_3(SiO_4)_3$		×	×	×		
Siderite, $FeCO_3$				×		
Silver, native, Ag				?	×	×
Smithsonite, $ZnCO_3$						×
Sphalerite, ZnS				×	?	
Sulphur, S						×
Tetrahedrite, $Cu_8Sb_2S_7$				×		
Titanite, $CaTiSiO_5$ or $CaO.TiO_2.SiO_2$	×					
Vanadinite, $(PbCl)Pb_4V_3O_{12}$						×
Wad, mixtures of oxides, chiefly of manganese, with water						×
Wulfenite, $PbMoO_4$						×
Zircon, $ZrSiO_4$	×					

ORE DEPOSITS

CLASSIFICATION

The ore deposits of the Breckenridge district were formed in one period of hypogene mineralization, and some of them were subsequently reconcentrated and modified by the action of surface water. The primary mineralization was directly related to the solidification of the quartz monzonite porphyry and was later than any of the porphyry intrusions in the region. Enrichment has greatly modified the original character of many deposits.

According to Ransome,[52] the differences in the ore deposits of the district are largely matters of mere size

[52] Ransome, F. L., op. cit., pp. 111, 112.

and shape of relative proportions of constituents rather than of essentially distinct types or periods of mineralization, and the relation of deposits of apparently diverse types can be traced through those of intermediate character. For convenience of description he grouped the deposits under the following heads:

(1) Veins of the zinc-lead-silver-gold series.
(2) Stockworks and veins of the gold-silver-lead series.
(3) The Farncomb Hill gold veins.
(4) Veins in the pre-Cambrian rocks.
(5) Metasomatic replacement deposits.
(6) Gold-silver deposits in the Dakota quartzite.

Deposits of the second and third classes are not present in the special area but will be briefly considered below. For this report it seems best to condense Ransome's classification and to summarize the general features of the ore deposits under the heads of (*a*) high-temperature deposits ("contact-metamorphic" ores) and (*b*) moderate-temperature deposits, including stockworks, veins, and blanket ores.

HIGH-TEMPERATURE ("CONTACT-METAMORPHIC") DEPOSITS

High-temperature deposits are generally regarded as having been formed under high pressures between temperatures of 300° and 500° C. The only ores in the district that come under this heading are the contact-metasomatic or "contact-metamorphic" ores, which are best developed on Gibson Hill. They are of too low grade to encourage development.

The "contact-metamorphic" deposits are related to crosscutting bodies of quartz monzonite porphyry and are best developed in limy beds. Limy beds occur in the Maroon, Morrison, and Niobrara formations, but the most favorable beds occur in the Morrison. Structurally the best conditions are found where the limy beds dip gently toward the cross-breaking body of quartz monzonite porphyry and are slightly fractured in directions nearly at right angles to the contact of the porphyry and the sediments. Strong gouge-filled faults or more open fractures that dip away from the contact with the porphyry are not structurally favorable for the formation of "contact-metamorphic" deposits.

These deposits are usually dense, irregular, tabular masses of silicates intergrown with metallic oxides and sulphides. The impervious character of the material as well as its chemical nature makes it resistant to weathering and enrichment. The garnetized limestone of the Morrison therefore stands out in the form of low cliffs on Gibson and Prospect Hills. (See pl. 4, *B*.)

"Contact-metamorphic" deposits cluster around the stocks that seem genetically related to their formation and differ from the veins in showing no general trend. In the Breckenridge district the proportion of metallization is small in these deposits, and extensive garnetization has occurred without the development of any ore. Where ore occurs it is usually small, spotty, and irregular in plan. Its inclination is that of the replaceable limy bed that formed the host rock and is therefore fairly regular. The ore commonly occurs in bunches, and its terminations may be very abrupt; but some of these bodies contain profitable ore which is rather evenly disseminated through them and grades through lean ore into the country rock.

In the zones of most intense metamorphism magnetite and hematite, although not abundant, are the chief metallic minerals present and were probably formed at high temperatures and high pressures, but chalcopyrite and pyrite were formed under pressures and temperatures only slightly less intense. The tonnage of copper ore in the district is small. The pyritic ores that are low in copper and of contact-metasomatic origin contain very little gold and cannot be worked below a shallow zone of enrichment, except where they grade into the pyritic galena blanket ores.

As distance from the mineralizing stock increases, the ore deposits lose their high-temperature characteristics and assume the appearance of deposits formed under moderate temperatures and pressures. Some deposits, such as the Sultana and Fox Lake, are evidently transitional between the blanket deposits considered on pages 32–33 and the "contact-metamorphic" deposits. It was impossible to study the ores of these mines during the visits of either Ransome or the writer, but it is known that some oxidized lead ore was shipped from them in the eighties and nineties. The sulphide ore exposed on the dumps at the present time is a heavy pyrite ore containing a little sphalerite.

MODERATE-TEMPERATURE (MESOTHERMAL) DEPOSITS

Stockworks.—The stockworks are practically confined to the quartz monzonite porphyry mass in the northeast quarter of the Breckenridge district and are not found in the special area studied by the writer. All the stockworks occur close to the axis of the regional syncline, and most of them lie about S. 60° W. of the place where the Williams Range thrust fault breaks away from the overturned fold that borders the pre-Cambrian terrane from Tiger to South Park. These shattered zones are younger than the quartz monzonite stocks, which in turn are younger than the thrust fault and most of the transverse faults. The stockworks therefore mark a late pre-ore adjustment along the dominant zone of weakness in the region. They probably mark the northern limit of the transverse belt effectively opened by northeast shear and tension fissures after the formation of the thrust fault, and thus they indicate the probable northern limit of profitable lode mining. (See "Structure", pp. 17–21.)

The following excerpts from Ransome's report [53] give the general features of these deposits, and the

[53] Ransome, F. L., op. cit., pp. 143–144.

reader is referred to the original report for further details:

A distinctive feature common to these deposits is the occurrence of the ore in much fissured and minutely veined rock, ordinarily quartz monzonite porphyry, rather than in well-defined lodes. The fissuring may vary widely in character. In the Hamilton ore bodies it is concentrated along nearly parallel zones, so that the pay shoots have a certain regularity and might be classed as stringer lodes having widths up to about 15 feet and being separated from each other by 50 feet or less of relatively barren porphyry. The ore as a whole, however, has no definite walls. The adjacent porphyry is also more or less fissured and contains many small stringers of sulphides.

In the Jessie mine there is not the same general agreement in direction of the fissures. Certain groups of them are approximately parallel, but these are associated with others having decidedly different strikes. In many places one set joins or crosses another without any general displacement of either. * * * At the Jessie mine a mass of porphyry, oval in plan, fully 900 feet long, 600 feet wide, and 300 feet deep, has been fissured in many directions, but especially by fractures striking from east to northeast. * * * There is generally no great persistency to these lodelike zones or stringers. Some die out within surprisingly short distances or merge with other zones. * * *

The deposits of this group yield generally a low-grade pyritic ore, concentrated principally for its gold and silver contents. There may be or may not be enough lead present to add to the value of the product. Mineralogically they consist of pyrite, sphalerite, and galena in a gangue of sericitized porphyry. Report indicates that the oxidized and partly oxidized upper portions of these deposits were considerably richer in the precious metals and in lead than the deeper sulphides, and it is known that bunches of rich ore containing galena and native gold were found in some of the upper workings. The greater part of the sulphides fills small open fissures, * * * but the veining is associated with some replacement. In the Jessie mine this metasomatism does not result in any general replacement of the porphyry by sulphides, so far as observed, but pyrite, sphalerite, and galena all develop sporadically at the expense of the orthoclase phenocrysts. In the Wire Patch ore bodies, however, the sulphides appear to have replaced the porphyry bodily to some extent.

Veins.—There are in the Breckenridge district from 25 to 30 veins that have each produced 1,000 tons of ore or more. Most of these veins lie in a short, narrow northeastward-trending belt, extending from Little Mountain to Mineral Hill, but a few, such as the Lauriam, lie slightly to one side. Smaller veins occur in this northeasterly belt and elsewhere in the district, but with the exception of the rich, narrow gold veins of Farncomb Hill none of them have contributed materially to the output of the district.

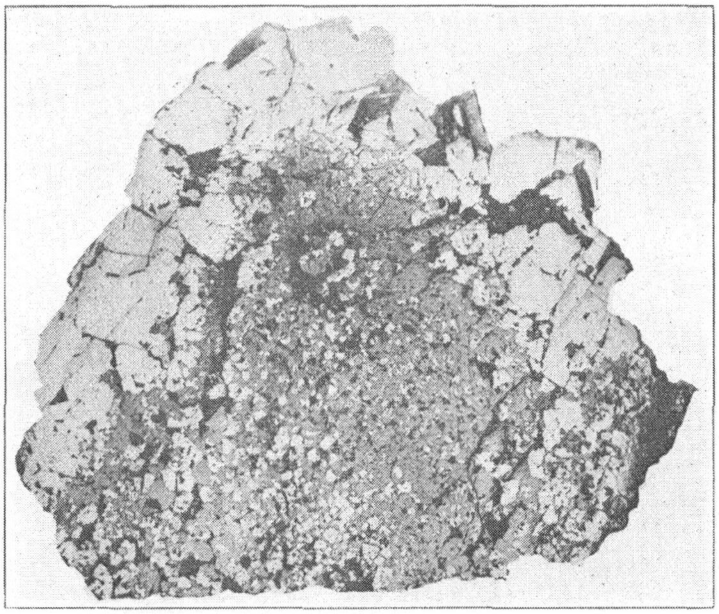
Nearly all the veins occupy premineral normal faults which strike N. 40°–80° E. and average about N. 65° E. They dip from 60° to 80°, and most of them show pronounced irregularities along their strike and dip. The undulations of the veins are illustrated in the plan and cross sections of the Wellington veins shown on plate 13.

Relation of veins to country rock.—The veins in the Breckenridge district cut all the bedrock formations, and the influence of the wall rock on the character of the ore is notable. Most of the ore in the district has come from veins in the monzonite porphyry and Dakota quartzite, but much ore has also been produced from veins in the quartz monzonite porphyry, Pierre shale, Niobrara formation, Benton shale, and Maroon formation. The writer does not know of any vein or blanket deposit that has produced ore from the Morrison formation, although, as stated on page 25, the limy beds are considerably replaced by contact-metamorphic minerals. Very little exploration has been done in the Morrison, however, and ore-bearing veins may occur in it.

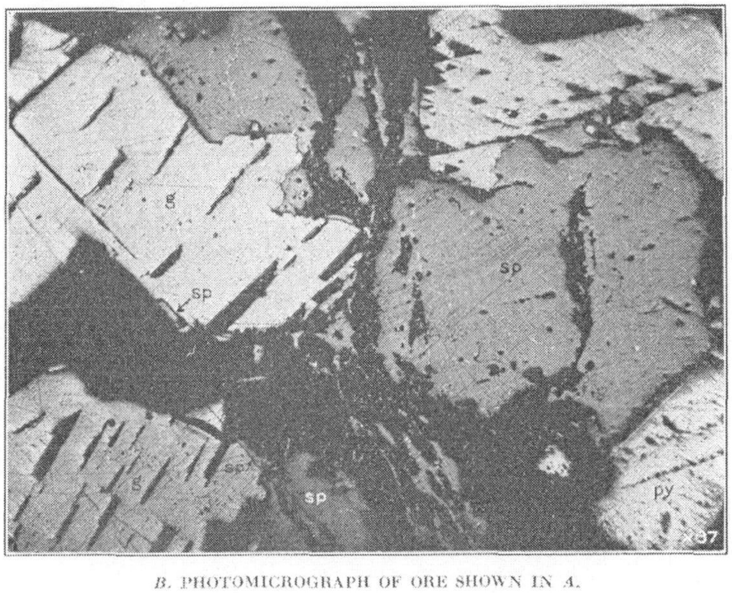
The influence of the wall rock on the veins is largely physical. Comparatively strong, brittle rocks, such as porphyry and quartzite, will break and form open fault breccias, whereas shale bends or forms tight, impervious clay-filled fissures. For these reasons ore solutions more frequently followed open channels along faults in the quartzite and porphyry than in the other rocks. In some places, however, as along the western part of the Wellington vein, the shales were hardened and strengthened by silicification before mineralization. In such places valuable ore shoots may be found between shale walls, and though the width of the vein almost invariably decreases on passing from porphyry into shale, the tenor of the ore commonly rises. If a vein along a fault fissure of small displacement is followed into shale, it commonly pinches out as the fault fades into a sharp flexure in the shale. A fault of large displacement, on the other hand, may contain ore in the quartzite or porphyry but become barren on passing into shale, although the fault itself persists for long distances between the shale walls. Faults that have a throw of 50 to 150 feet are more likely to contain ore in shale than those of greater or less displacement. Even in strong rocks, such as porphyry and quartzite, faults that show displacements of more than 300 feet produced large amounts of nearly impervious gouge. In premineral faults of this class the ore occurs in bunches and chimneys, is commonly brecciated by later movements, and consequently is often mistaken for "drag ore" from some faulted vein.

The chemical character of the wall rock is much less important in determining the presence of ore than its physical properties. Certain limy beds in the Cretaceous rocks are slightly replaced next to some veins. In general the replacement deposits are largely pyritic and of too low grade to be mined profitably. These replacement deposits are intermediate between the veins and the blanket deposits described in the next section but have not proved of commercial value.

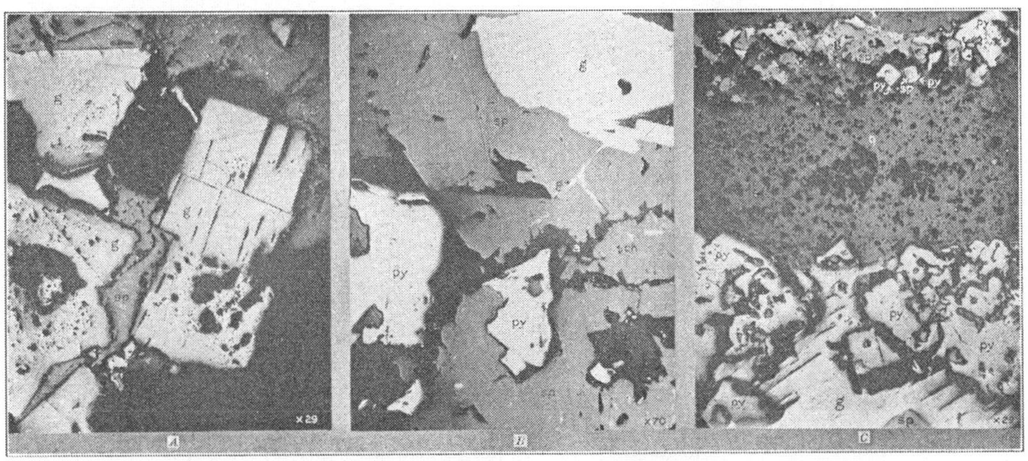
Ore channels.—The faults having large displacements persist to greater depths than the faults of small movement. Thus the strongest pre-mineral faults should tap the deep upward-moving ore solution first and act



A. ORE FROM SPUR VEIN, WELLINGTON MINE.
About 200 feet from surface, near junction with Main vein.



B. PHOTOMICROGRAPH OF ORE SHOWN IN *A*.
Showing solution cavities. g, Galena; sp, sphalerite; py, pyrite.



A. LATE SPHALERITE CEMENTING AND REPLACING BRECCIATED GALENA, SPUR VEIN, WELLINGTON MINE. *B*. LATE GALENA FOLLOWING CRYSTAL BOUNDARIES OF EARLY SPHALERITE, WELLINGTON MAIN VEIN AT WINZE, LEVEL 8. *C*. REPLACEMENT ORE FROM LEVEL 8, WELLINGTON MINE.

g, Galena; sp, sphalerite; py, pyrite; a, ankerite; ch, chalcopyrite; q, quartz.

as guides in their subsequent journey. There is a striking relation between the Great Northern-J fault and the ore bodies in the veins on the east side of the Wellington ground. (See fig. 20.) A similar relation exists between the Bullhide fault and the veins on the west side of the property. Ore solutions under high temperatures and pressures probably followed an intricate course through local channels in the wide zones of selvage that mark these large faults and passed into the more open channels of moderate-sized faults at the first opportunity. The more open character of these newly reached fissures and the large area of their walls, which appreciably cooled the solutions, were evidently effective in causing the deposition of the primary sulphide ores. The localization of ore shoots was further influenced by the ease of movement in different directions in the more open fissures. It is evident that movement of the irregular surfaces forming the fault walls resulted in openings in some places and the squeezing and grinding of the walls in others. The ore solutions would follow the easiest road to the areas of low pressure and travel through the most open channels available, thus localizing ore shoots in the more open parts of the faults of moderate movement. In some places small gouge-filled cross faults displace the veins and apparently cause a notable change in the vein filling on each side. The ore is commonly wider than the average on one side of the cross fault and much narrower on the other. In many places it is clear that the cross fault is premineral and that either the cross faulting has dragged the vein walls together on one side while pulling them apart on the other or that the gouge seam has acted as a baffle and deflected the mineralizing solutions away from the barren zone found on one side of the fault.

Mineralized sheeted zones usually contain one major vein and one or more parallel minor veins. The minor veins are irregularly distributed and lack persistence. The major vein may thin out at the place where a parallel minor vein thickens, but more commonly the major vein is continuous and consistently follows the footwall or the hanging wall of the sheeted zone.

Character of the primary ores.[54]—The primary ores of the Breckenridge district consist largely of lead, zinc, and iron sulphides, with some native gold and some silver whose form in the primary ores is uncertain. The most common gangue minerals are ankerite, calcite, quartz, and sericite. Copper is a minor constituent of most of the ores but is locally abundant in the narrow gold veins of Farncomb Hill.

Pyrite is the most abundant and widespread of the sulphides, occurring in the high-temperature deposits close to the quartz monzonite stock north of Nigger Hill, in the zinc veins a short distance east of it, in the mixed lead-zinc ores nearby, and to some extent in the high-grade galena shoots found scattered throughout the district. Sphalerite is also very abundant and is a moderately persistent mineral, although it is uncommon in the high-temperature deposits and in the essentially lead ores. Galena is rare in the high-temperature deposits and is more abundant in the upper part of some mixed lead-zinc ores than in depth. In others it apparently has as great a vertical range as sphalerite.

The ores of the high-temperature or "contact-metamorphic" deposits are not economically important and have not been exploited enough to give any information on their changes with depth.

The pyritic sphalerite veins are illustrated by the Great Northern vein of the Wellington mine, which is the only one in the district that was essentially a zinc ore throughout. The lead content of this vein was less than 2½ percent at the surface. Pockets of galena occurred here and there throughout the vein, but the average lead content of the ore decreased with depth from 2½ percent at the surface to less than 0.5 percent near the bottom of the ore shoot. The bulk of the ore was a pyritic zinc blende, which changed abruptly into nearly pure pyrite at the bottom and at the east end of the shoot. The sphalerite contains more than 10 percent of iron and should be classed as marmatite. The silver and gold content of the ore was very low. Comparatively little gangue was found in the vein, and it consisted chiefly of sericitized wall-rock inclusions and ankerite.

The primary zinc-lead ores differ from the ore just described in having a much larger proportion of galena throughout the vein and in passing upward rather abruptly into a zone of sphalerite-free galena near the surface. Below the upper galena zone the lead content of the primary ore generally decreases slowly with depth. Little gangue is found in the sulphides, but siderite veinlets are locally abundant where movement subsequent to the deposition of the sulphides has reopened or brecciated the ore. Siliceous gangue material is uncommon. The sulphides are generally massive and show no evidence of depositional banding or crustification, although light-colored veinlets of ankerite parallel to the walls in places give the ore a slightly banded appearance. (See pl. 14, *B*.)

The primary ore of the thin gold veins on Farncomb Hill is a mixture of pyrite, galena, sphalerite, and chalcopyrite in various proportions, accompanied by native gold in a calcite gangue. At other places in the district gold is found in veins made up dominantly of pyrite but containing some zinc blende and galena. In general the gold deposits are associated with calcite and quartz gangue, in contrast to the lead-zinc veins

[54] Ransome (op. cit., p. 111) applied the word "primary" to all lode deposits as distinguished from detrital or placer deposits. As the present writer is dealing only with the lode deposits, he is following the more common practice of calling original, hypogene ores primary and distinguishing them from ores that have undergone secondary or supergene changes, either in the oxidized zone or in the zone of sulphide enrichment.

low in gold, which generally have ankerite and siderite as gangue minerals.

Relation of veins and ore to topography.—In a few places rusty, silicified vein outcrops can be traced for some distance on the surface, but generally the veins are hidden beneath a cover of slope wash or gravel. However, most of the veins were found by prospecting based on the distribution of rich oxidized "float" ore at the surface, although some highly productive veins, such as the Great Northern, remained unknown until found in the course of underground development.

The relation of ore shoots to topography is somewhat complicated by the original distribution of ore minerals and by the work of downward-moving waters in post-Eocene time. Ore shoots that are made up chiefly of the comparatively soluble minerals pyrite or sphalerite show little or no relation to topography other than that they lie below the zone of Tertiary oxidation. Galena, however, shows a rather definite relation, though interpretation of this relation is not simple.

Ransome [55] noted that all the high-grade galena ore had been found within 300 feet of the surface and says:

> Even the imperfect data now available establish without much question the limitation of the lead ores to a zone ranging from 200 to 300 feet deep and corresponding roughly to the present strongly accented topography. * * * All available evidence indicates that in this district 300 feet, or perhaps more safely 400 feet, is the limiting depth for the occurrence of considerable bodies of essentially galena ore as opposed to sphaleritic or pyritic ores.

No high-grade lead ore has been opened below this depth since Ransome's visit.

Most of the rich lead ores so clearly related to the surface probably resulted from the leaching of lower-grade mixed sulphide ores. Both sphalerite and pyrite are soluble in meteoric waters and tend to disappear from the upper parts of the veins, while galena, protected by a thin but comparatively insoluble coating of lead sulphate, remains.

Mixed lead-zinc ores have a much greater range than the high-grade lead ore. In the Wellington mine they show little relation to the topography and are known to have a vertical range of more than 800 feet. The upper parts of these veins, however, are richer in lead than the lower parts, and the shoots of lead ore conform to the topography in a general way.

The zinc ores show a negative relation to the topography. Practically no zinc has been found in the upper parts of veins that come to the surface in areas where the preglacial topography is well preserved. (See pl. 4, *B*.) The most productive zinc veins, such as the Great Northern, Country Boy, and Sallie Barber, are well down the slopes of French Gulch, several hundred feet below the level of the Tertiary land surface. This relation may be accidental, but the writer believes that it reflects the leaching of the readily soluble zinc sulphide above the Tertiary ground-water level.

[55] Ransome, F. L., op. cit., p. 167.

The rich gold ores bear a positive relation to the surface compatible with their secondary origin. Rich gold veins are not found in the floors of the large valleys but are closely associated with the tops of the hills, which represent the remaining parts of the old Tertiary land surface. This is true not only of veins, such as those on Nigger Hill and Farncomb Hill, but also of the blanket deposits, such as those on Schock Hill, Little Mountain, and Gibson Hill. The rich gold ore is limited to the oxidized zone, and most of the gold produced in the district has come from depths of less than 350 feet.

SUPERGENE ENRICHMENT

After careful study of the district Ransome [56] concluded that most of the native gold and much of the galena were concentrated by the agency of surface water, but there has been a general reluctance on the part of miners and geologists to accept this part of his report. The present writer believes that much of the native gold and some of the galena are secondary but that most of the galena and essentially all the sphalerite are primary. The evidence that has led the writer to these conclusions is presented below.

Criteria of enrichment in the Breckenridge district.—Before discussing the Breckenridge deposits further it will be advisable to consider the criteria of enrichment. Lindgren [57] concurs with Ransome [58] that—

> the best geological evidence of enrichment consists in the progressive, uniform impoverishment of all similar deposits in a given district, coupled with the condition that the change in ore should be dependent upon postmineral topographic development.

Several additional criteria are suggested by Emmons: [59] A secondary ore is commonly porous and open-textured; it is later than the primary ore and may form in cracks cutting the earlier ore or replace it along such cracks; a leached zone near the surface, grading downward into a zone of higher-grade sulphide and this into a leaner ore zone, suggests enrichment; metals that are reprecipitated are those that go into solution and consequently are those that are leached from the outcrop; the presence of groups of minerals known to be characteristic of enrichment in other deposits is suggestive; the vertical extent of a secondary sulphide zone should show a relation to the composition and permeability of the primary ore. A detailed study of the paragenesis of an ore may be helpful, although hypogene sulphide replacement is very common and may be difficult to distinguish from supergene replacement.

[56] Ransome, F. L., op. cit., pp. 169-170.

[57] Lindgren, Waldemar, Mineral deposits, 3d ed., p. 934, 1928.

[58] Ransome, F. L., Criteria of downward sulphide enrichment: Econ. Geology, vol. 5, pp. 205-220, 1910.

[59] Emmons, W. H., The enrichment of ore deposits: U.S. Geol. Survey Bull. 625, pp. 81-83, 1917.

Enrichment of zinc.—The most significant criterion of enrichment is the relation of the ore to the post mineral topography, which has been discussed briefly on page 28. The negative relation of the zinc ores to topography and the gradual instead of abrupt increase of sphalerite with depth clearly reflect leaching of zinc sulphide from the outcrops and its dissipation by ground water at depth. The porosity developed in mixed lead zinc ore close to the surface by the leaching of sphalerite is illustrated in plate 6, *B*. The lack of replaceable limy beds near the ore bodies prevented the fixation of zinc as the insoluble smithsonite. Insignificant amounts of calamine and of late light-colored sphalerite that may be of supergene origin have been noted, but no commercial quantities of zinc ore were formed by enrichment in the Breckenridge district.

Enrichment of lead.—The relative insolubility of lead sulphide, lead carbonate, and lead sulphate during the weathering of mixed sulphide ores causes these compounds to linger in the oxidized zone, and residual galena is common in the outcrops of veins. As a result, it is commonly thought that lead deposits become enriched chiefly through the removal of soluble material, which leaves the lead compounds as residual concentrates in the upper part of a vein, and very little mobility is ascribed to lead in the weathering of a vein. Galena is tacitly assumed to be primary unless there is strong evidence to the contrary, and so a somewhat detailed consideration of its occurrence and alteration is given.

In all the productive lead mines in the district cerusite with more or less galena occurred at the surface. This oxidized ore commonly passed downward into a sulphide zone rich in galena, but probably nowhere in the district has this rich lead ore been found more than 350 feet below the surface. The longitudinal sections and stope maps of the mines described on pages 41–44 are convincing illustrations of the fact that rich lead ores are restricted to a comparatively shallow zone.

The uniform impoverishment of the essentially lead veins at shallow depths is shown by the records of the Old Reliable, Cincinnati, Union, Lucky, Iron, Wellington, Prize Box, Iron Mask, Ohio, Minnie, Ella Kellog, Washington, Mayo, Dunkin, Puzzle-Ouray, Germania, and Golddust veins. The relation of the cerusite in these veins to the old land surface is accepted as a consequence of its secondary nature; the parallel relation of galena to the ancient topography cannot be regarded as accidental and is the reason for Ransome's conclusion that "a large proportion of the galena in the Breckenridge ores is the result of downward concentration by atmospheric water." [60]

[60] Ransome, F. L., op cit. (Prof. Paper 75), p. 169.

The criteria of enrichment listed from Emmons' work can be conveniently grouped under texture, paragenesis, and downward changes in minerals.

The shallow galena ores seen by the writer are conspicuously open textured, and although the primary ore exposed in the deeper workings of the Wellington mine is porous, it is much less open textured than the shallow galena ore. (See pl. 6.) Many of the openings in the shallow ore are cavities left by the removal of zinc blende. Remnants of sphalerite can be seen in the openings in shallow ore of the Wellington vein, as illustrated in plate 6, *B*. According to experiment and observation,[61] sphalerite is one of the most readily soluble of the common sulphide ores, and in the zone of oxidation the sulphides are dissolved in the order (1) sphalerite, (2) chalcopyrite, (3) pyrite, (4) galena It is difficult to estimate how much of the porosity of the shallow ores has resulted from leaching, but it is plain that the open texture is no proof of the secondary nature of the galena and pyrite present.

A study of the paragenesis of an ore may be very helpful in working out the problem of its origin. Some investigators believe that certain types of microscopic intergrowths and textures are found only in supergene deposits and that others are confined to primary ores, but there is disagreement on the meaning of many textural relations. A study of the problem with a reflecting microscope is not conclusive, but no evidence of secondary galena was found. The relation of galena to the other sulphides in the shallow ores is discussed on page 56 and illustrated in plate 7. Coarse cubical galena coated with films of late fine-grained pyrite is abundant and is earlier than some medium-grained pyrite and dark sphalerite that contains many small blebs of chalcopyrite. (See pl. 7, *A*.)

The downward changes in an ore deposit are of great aid in determining the origin of the different mineral zones.

In the Breckenridge district the primary ores contain very little copper, and the small amount present commonly occurs in erratic bunches of chalcopyrite in the lead-zinc ores, in small masses in the contact-metasomatic ores, and as an evenly disseminated constituent in the thin gold veins of Farncomb Hill. The upper parts of the lead veins carried more silver than the lower parts of the same veins. In a few places some secondary copper sulphides have been found near the outcrop, associated with masses of galena, but this may pass downward into a mixed lead-zinc ore, a nearly pure sphalerite ore, or a heavy pyritic material containing very little zinc. In primary ores sphalerite would normally increase with depth, but a change from galena to pyrite low in zinc is less common in the

[61] Emmons, W. H., The enrichment of ore deposits: U.S. Geol. Survey Bull. 625, p. 131, 1917.

primary ores of a lead-zinc district. It is probable, however, that zinc was originally present in all the ores and has been completely leached from the veins now showing galena ores bottoming in pyrite.

As galena is more abundant in the upper part of a primary galena-sphalerite-pyrite ore shoot, and as sphalerite and pyrite are leached from the oxidized zone much more rapidly than galena, it follows that galena should invariably be much more abundant than sphalerite and pyrite near the surface, unless the rate of erosion was too fast to permit the leaching of pyrite and sphalerite. Whether the veins suffered little or much erosion, the ore consisting essentially of lead would probably appear related to the surface unless primary galena ore shoots went to great depths.

Thus in attempting to apply the criteria of sulphide enrichment to the galena ores of the Breckenridge district, only two—relation to surface and open texture—are of any significance, and even these may be rather satisfactorily explained by the leaching of more soluble minerals from a primary ore.

However, if it were not for the comparative insolubility of secondary lead minerals the downward changes in the ores of the Breckenridge district would be as compatible with the theory that much of the galena is secondary as with the opposite theory of primary origin. Therefore, a brief discussion of possible lead solvents is given below.

Solvents of lead minerals.—The search for lead solvents must be restricted to the solutions that may be expected to occur in nature in the Breckenridge district. Carbonated waters, chloride waters, sulphate waters, alkaline-earth waters, and water containing organic acids are the only meteoric solutions that are likely to have affected the veins. The solubility of the carbonate, sulphate, and sulphide of lead in pure water is low, but the chloride is moderately soluble. Both the sulphate and the chloride are moderately soluble in concentrated brine solutions, but their solubility in weak chloride solutions is less than in pure water.[62] Strong chloride waters could be present only under very arid conditions, but the Tertiary history of the region shows that aridity may have prevailed in the later part of the Pliocene epoch. Throughout nearly all post-Cretaceous time, however, the Breckenridge district had a moderately humid climate, and it is unlikely that much lead was moved in chloride solutions. Waters that contain the carbonate radicle, especially as bicarbonates of the alkaline earths, are effective precipitants of lead salts and need not be further considered. Oxidizing sulphate waters, which are abundant in many of the veins in the district, react with galena to form lead sulphate, which is only sparingly soluble (41 parts per million) but is nevertheless 21 times more soluble than the carbonate, and this in turn is slightly more soluble than the sulphide. A solution of bicarbonate of lead is formed from lead carbonate in the presence of free carbon dioxide, and the solubility of the carbonate is directly related to the concentration of carbon dioxide in the water. The solubility of lead carbonate in a solution saturated with carbon dioxide[63] is slightly less than that of lead sulphate in pure water, and it is unlikely that the concentration of free carbon dioxide ever approached saturation in the ground water. The abundance of lead carbonate in the oxidized zone suggests that the carbon dioxide was combined with alkaline-earth metals and that lead carbonate was precipitated instead of transported.

[62] Ralston, O. C., Hydrometallurgy of lead: Am. Inst. Min. and Met. Eng. Trans., vol. 70, pp. 447–449, 1924.

[63] Siebenthal, C. E., Zinc and lead deposits of the Joplin region: U.S. Geol. Survey Bull. 606, p. 53, 1915.

It has long been known that lead carbonate is soluble in certain organic acids. A cold-water extract of decaying pine needles was prepared by the writer and was tested as a solvent for lead sulphate, lead carbonate, and lead sulphide by R. C. Wells of the United States Geological Survey. The equilibrium solubilities of these compounds in grams per liter, as determined by Mr. Wells, together with their solubility in pure water, are given in the table below.

Solubility of lead compounds (grams per liter)

	Pine extract	Water
Lead carbonate	0.2100	0.0019
Lead sulphate	.0215	.0410
Lead sulphide	[a].0089	[a].0013

[a] Lead weighed and reported as lead sulphate.

The solubility of the carbonate in the pine extract is greater than that of lead compounds in any other probable natural solution. A pound of lead carbonate would require 540 gallons of the pine extract to dissolve it, whereas 2,900 gallons of pure water is needed to dissolve a pound of lead sulphate, the next most soluble compound that can be considered in the Breckenridge district. Lead sulphate and carbonate are also readily soluble in solutions of ammonium acetate, calcium acetate, or magnesium acetate, and some of these substances would be present in the soil solutions after they came in contact with the carbonate gangue of the vein. As it is probable that this region has been forest-clad ever since the Laramide revolution, organic acids from decaying vegetation have probably been present in the ground water throughout the time that the veins have been undergoing erosion.

Leaching of the veins.—The open texture of oxidized ore favors the rapid passage of ground water from the surface to the level of the water table, and the upper part of a vein commonly forms a persistent, porous crevice, which drains the surface for considerable distances on both sides of its outcrop. The ample flow of water from adits driven along veins indicates that the circulation of ground water is very active in these veins at present. There is little doubt that during the Tertiary period there was time for a large quantity of ground water to sink through the veins to the water table. It is very improbable that the ground water carried as high a percentage of organic acids as the pine extract or that it would become saturated with lead salts before it reached the water table. If only a small amount of an ore shoot has been eroded and ground water has always been close to the surface, only a small amount of lead would be exposed to oxidation, and no matter how much water passed through the outcrop only a small amount of lead could be moved. Thus the actual amount of lead dissolved would be many times less than that theoretically possible. Nevertheless it is quite certain that very appreciable amounts of lead could have gone into solution since Eocene time.

Precipitation of lead.—In spite of the comparative insolubility of lead minerals it is reported that secondary galena may be formed rapidly. In the Mission mine, near Lincolnville, Okla.,[64] crystals ranging from one fiftieth to one half inch in diameter were deposited on iron spikes and tools that had been submerged during a 2-year period of idleness. Wheeler believes that the galena was precipitated from lead solutions through the reducing action of the iron. The iron spike shown in his paper was strongly altered to limonite; sand and angular pieces of chert, the largest half an inch in length, as well as galena, are cemented to the spike by this limonite. Most of the galena crystals were less than a quarter of an inch in diameter, but two crystals about half an inch long are present. One of these large crystals is beside a ½-inch fragment of chert, which Wheeler suggests was lying on the bottom of the drift, and it therefore seems just as probable that the galena was also lying on the bottom of the drift. The other large piece of galena is separated from the metallic iron by about a quarter of an inch of chert-bearing limonite. As the chert and sand indicate transportation by moderately strong currents, it seems probable that much of the galena was also mechanically transported and was entrapped by the cementing limonite. Rapid precipitation of galena from mine waters does not seem clearly established.

Experimental work shows that hydrogen sulphide immediately precipitates lead sulphide from solutions of organic lead compounds, lead sulphate, or lead bicarbonate. Sulphate solutions immediately precipitate lead sulphate from a pine extract. Solutions containing carbon dioxide or alkaline-earth carbonate will precipitate lead carbonate from a solution of lead sulphate if no free acid is present, but if a small amount of free organic acid is present carbon dioxide will not precipitate solutions of lead. Similarly, solutions of alkali carbonates, after neutralizing any free organic acid, precipitate lead carbonate.

Probable reactions in the vadose zone.—In a galena-sphalerite-pyrite vein cold oxygen-bearing waters first attack sphalerite, convert it to the sulphate, and leach it from the upper part of the vein. Galena has a lower oxidation potential than pyrite and therefore tends to change to the sulphate before pyrite is oxidized. However, as soon as a protective coating of the insoluble, poorly conducting sulphate has formed on the galena, it oxidizes more slowly, and the oxygen-bearing waters start their attack on pyrite. Some of the pyrite is oxidized to inert limonite, but much of it is converted into ferric sulphate and sulphuric acid, which are mobile and move down toward the water table.

Lead sulphate is more soluble than the carbonate, and the sulphate shell surrounding the galena masses is converted to the carbonate by water containing carbon dioxide or alkaline-earth carbonates. As ankerite is present in most of the lead veins and in their altered wall rocks, the ground water soon contains carbonates and bicarbonates of lime and magnesia, which can react with the slightly soluble lead sulphate. In many places galena is apparently converted directly to cerusite, but it is probable that a submicroscopic film of sulphate intervenes between the sulphide and carbonate.

At the surface there is commonly a layer of decaying pine needles which supplies organic acids to the water soaking through it. The results of Harrar's work[65] suggest that organic acids dissolve limonite much more slowly than lead carbonate. Thus the lead carbonate near the surface would be attacked by the compounds extracted from the pine needles and go into solution while limonite remained behind. Unless this solution were moving very rapidly or escaped an appreciable contact with ankerite or some other neutralizing substance, the dissolved lead would soon be reprecipitated as the carbonate. In the places where lead solutions reached the lower part of the vadose zone they might be reprecipitated as sulphate, carbonate, or sulphide. If any hydrogen sulphide were present lead sulphide would be precipitated regardless of the presence of sulphates or carbonates. As dilute sulphuric acid attacks sphalerite and the other sulphides, with the evolution of hydrogen sulphide, it is probable that the lead would be precipitated as galena. The chemistry of lead in a galena-sphalerite-pyrite-ankerite deposit within the reach of meteoric water, as sketched above, suggests that in the Breckenridge district moderate amounts of lead were dissolved and reprecipitated near the surface

[64] Wheeler, H. A., The rapid formation of lead ore: Am. Inst. Min. Eng. Trans., vol. 63, pp. 311-323, 1920.

[65] Harrar, N. T., Solvent effects of organic acids on oxides of iron: Econ. Geology, vol. 29, p. 55, 1929.

in the form of cerusite, but that little secondary galena was formed.

It must be recognized that enrichment processes are cyclic and depend largely on climate and topography. The general nature of the Tertiary period has been discussed on pages 22–23, but the placers bear witness that at times erosion overtook the tops of the veins and swept away much valuable material. At other times the downward concentration of the metals proceeded with greater rapidity, and some lead was carried down and reprecipitated, chiefly as carbonate but to a less extent as sulphate and sulphide.

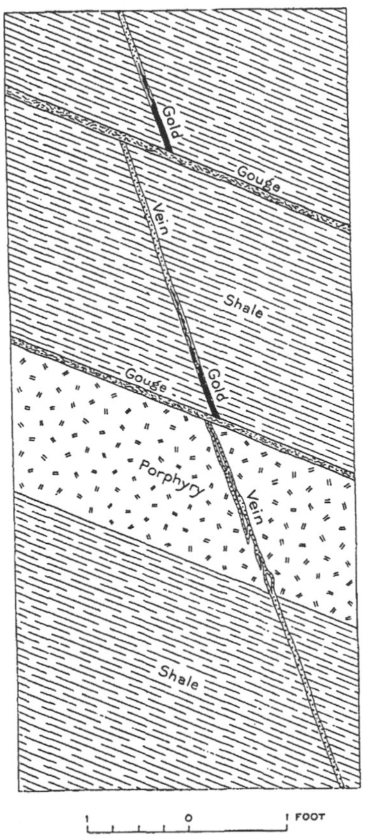


FIGURE 5.—Generalized section of Farncomb Hill gold vein. After Ransome.

In conclusion, it seems that the evidence for the residual enrichment of the lead ores in the Breckenridge district is established by their relation to topography and supported by their mineral changes in depth but that some solution and reprecipitation have also occurred. Carbonated waters are shown to be an inadequate agent for the transportation of an appreciable amount of lead, but a considerable quantity was probably carried as organic compounds, a small amount as sulphate, and only very minor amounts in the form of chloride. Most of the lead was reprecipitated as cerusite, but some secondary galena may have formed.

Enrichment of gold.—The enrichment of gold is easily demonstrable. It is closely related to topography, and it is definitely concentrated in the Farncomb Hill veins at the intersection of postmineral bedding-plane slips, as shown in figure 5. Its occurrence in the Dunkin vein is clearly related to the presence of the impervious shale underlying the open fissure in the porphyry and indicates the reaction of downward-moving solutions with reducing material in the shale. (See fig. 12.)

Although the gold is unquestionably concentrated by the agency of surface water the solvent that was effective in its solution has not been determined. Ransome [66] was unable to suggest an effective agent. Emmons [67] believes that chlorine is essential for the solution of gold and that the presence of manganese is almost necessary to release chlorine from chlorides. The primary gold ores contain manganese, but chlorides are not abundant enough in the present humid climate to furnish a source of the necessary chlorine. If the mechanism suggested by Emmons caused the gold enrichment, which is clearly related to the Tertiary land surface, it must have operated during a former arid climate, when chlorides would have been abundant. The only arid stage in the Tertiary history of the region is believed to be the late Pliocene, but it is very doubtful if even at that time the mountainous western slope of the Front Range, where the Breckenridge district lies, would have been so arid that the ground waters were briny. The work of Freise [68] shows that gold is soluble in humic acids derived from decaying vegetation if no oxygen is present. It seems probable that solutions similar to the pine extracts of the writer were generated through much of the Tertiary and Quaternary periods and were probably the effective solvents of gold in the Breckenridge district.

BLANKET DEPOSITS

Mineral deposits that lie along bedding planes are locally known as "contacts" but will be described in this report as blanket deposits, or simply "blankets", because of the more widespread use of that term. Both primary and secondary mineralization are represented in the blanket deposits of the Breckenridge district, but the valuable concentrations were apparently caused by the action of surface water.

Relation to country rock.—The blanket deposits are practically confined to Gibson Hill, Schock Hill, and Little Mountain and occur in replaceable beds of the Maroon formation and the Dakota quartzite. It is possible that the limy beds of the Morrison formation contain blanket deposits also, but none were observed by the writer. The discontinuous character of the beds in the Maroon formation suggests that layers containing ore would not be persistent, and thus the value of finding their exact stratigraphic position is questionable. At the Sultana and Fox Lake mines the ore follows replaceable beds close to the bottom of the Maroon formation, but the stratigraphic position of the other blanket deposits in this formation is not known.

On Little Mountain the blankets occur in both the middle and lower members of the Dakota quartzite, whereas on Gibson Hill the valuable deposits are found chiefly in the middle shaly member. Blanket deposits

[66] Ransome, F. L., op. cit., p. 170.
[67] Emmons, W. H., op. cit., p. 308.
[68] Freise, F. W., Transportation of gold by organic underground solutions: Econ. Geology, vol. 26, pp. 421–431, 1931.

are not known in any formations younger than the Dakota.

Relation to structure.—The blanket deposits are not related to strong faults or veins. The most favorable situation for large replacement deposits seems to be at the upward termination of minor veins. It is probable that a large open vein permitted such easy passage for ore solutions that they had little reason for following replaceable beds where these were intersected by the vein; on the other hand, if a fissure filled with ore solutions died out in a series of replaceable beds the solutions would be forced into an intimate contact with these beds that would be highly favorable for the formation of ore deposits of minable proportions.

Character of the ore.—In Little Mountain the primary ore probably consisted of gold and silver accompanied by pyrite. Weathering has changed the primary ores here into spongy masses of limonite with a relatively high content of gold and silver. The ore occurs in small bodies, and the richest masses were found in pockets along the bedding planes close to the surface.

In Gibson Hill the blankets contain both primary and seconday ore and are much larger than the deposits on Little Mountain. The primary ore is a mixed pyritic lead-zinc ore containing both gold and silver. In some places native gold and native silver have been found coating galena in the oxidized zone. "Mud" seams, consisting of altered rock selvage along bedding-plane slips, are mined for their gold content in some places, and the adjoining quartzite wall rock contains varying amounts of gold disseminated through it. No evidence of mineralization can be seen in the gold-bearing quartzite in these places, and the presence of the metal can be determined only by an assay. Little is known of the character of the ore at the west base of Gibson Hill in the blanket deposits in the Maroon formation. In general these were also pyritic lead-zinc ores, having a shallow zone of galena and cerusite, and some of the material on the dumps suggests that the mineralization was intermediate between that of the deposits formed at moderate temperatures and that of the deposits formed at high temperatures. Specular hematite, epidote, and chlorite are associated with pyritic zinc ore in some of the latest material mined.

On Schock Hill shallow high-grade gold ores were found similar to those in Little Mountain, and some deeply weathered lead deposits resembling the deposits of Gibson Hill were also exploited. Some pyritic zinc ore was found in the Finding shaft and suggests the same downward changes observed in the blanket deposits in the Maroon formation at the west base of Gibson Hill.

MINE DESCRIPTIONS

COUNTRY BOY

The Country Boy mine is about 1½ miles east of Breckenridge on the south side of French Gulch directly across from the Wellington mill. (See pl. 4, *B*.) The mine has been operated intermittently since about 1889, and the known production is given in the table on page 60. It is said to have produced, when first opened, a high-grade lead-silver ore carrying some gold, but it is best known for the high-grade zinc ore that has made up the bulk of the production.

The mine was not accessible in 1928, and the following summary is taken from Ransome's report.[69]

The mine is opened by two adits about 170 feet apart vertically and not connected by raises underground. The upper tunnel, at an altitude of about 10,000 feet, runs S. 18° E. for 700 feet and then turns slightly and continues in a S. 25° E. direction for about 1,000 feet more. This tunnel cuts the Country Boy vein between 400 and 450 feet from the portal and is connected with drifts and stopes on the vein, most of which are inaccessible. At 350 feet beyond the Country Boy vein a drift turns off on the Hite vein, which was being prospected at the time that Ransome's report was made. The lower tunnel runs southeast for 1,050 feet to the Country Boy vein, where it connects with short drifts and stopes.

The thick monzonite porphyry sheet of Nigger Hill frays out near the Country Boy mine into a series of northeastward-dipping sills that intrude the Niobrara, Benton, Dakota, and Morrison formations. The whole mass has been strongly faulted, but unfortunately the rocks are very poorly exposed, and it is difficult to make out the exact relations. The triangular patch of black shale near the mine is probably in large part Niobrara, as the thickness of limy shale underground suggests that the Benton does not appear at the surface here. The shale is intruded by a monzonite porphyry, which crops out at the portal of the upper tunnel. Both shale and porphyry are cut by a strong northerly fault that offsets the west side to the south. The throw of the fault is probably less than 300 feet. This fault may be a continuation of the Great Northern fault zone of the Wellington mine. The throw is apparently less at the Country Boy mine, but the relations are so obscure that it is possible to point out only the most probable of the many possible interpretations of the areal geology. The wedge-shaped area of black shale east of this fault is probably Benton and is limited on the southeast by the Country Boy fault vein, which brings Dakota quartzite against it. The Dakota quartzite in turn is limited on the southeast by another fault,

[69] Ransome, F. L., op. cit., pp. 134-136.

which brings monzonite porphyry against the quartzite. In all these faults the downthrown side is on the northwest or west. Apparently the porphyry sill southeast of the Country Boy vein is underlain by the gray shale of the Morrison about 300 feet below the surface. The general dip of the gray shale is about 17° NNW., and the dips of the black Cretaceous shale range from 25° to 50° N. or NE.

The Country Boy vein strikes approximately northeast and dips on the average about 80° NW. Where Ransome examined the vein, it was entirely in monzonite porphyry and had a maximum width of about 5 feet. The ore consisted of dark sphalerite with very little gangue material and graded into pyritic ore at both ends of the 250-foot stope on the lower level. Galena is rare in this level and occurs only in small bunches less than 5 inches in diameter. Most of the ore cements and replaces crushed porphyry in a zone of fissuring and brecciation, but some of it fills clean-cut fissures in the porphyry. The boundary between the vein and the country rock is usually very definite, but the wall rock shows marked metasomatic alteration and contains pyrite and sphalerite in veinlets and disseminated crystals. Where the ore pinched

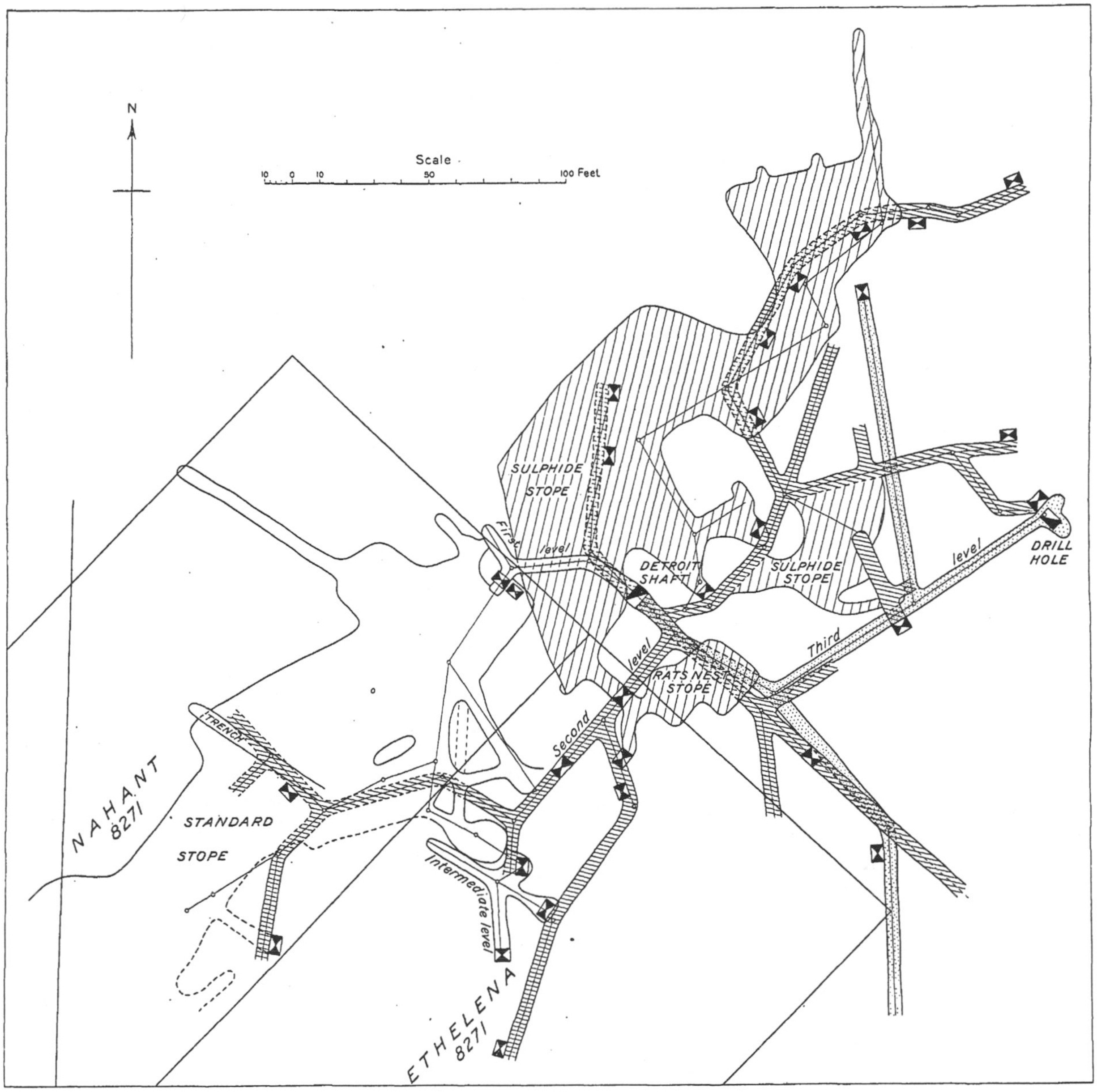
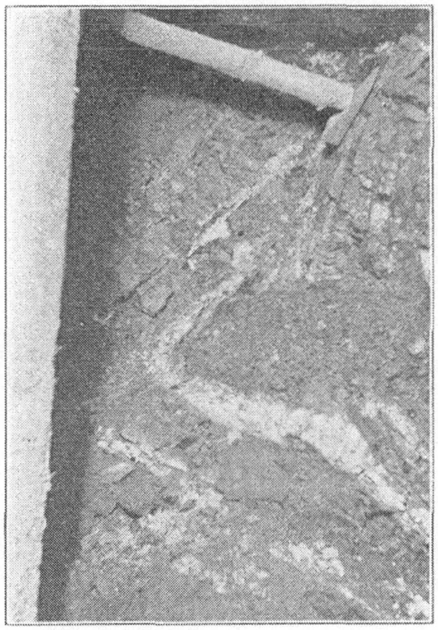
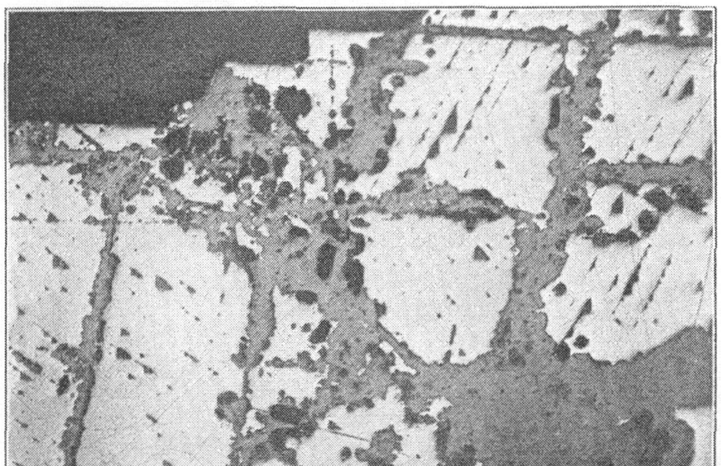


FIGURE 6.—Map of Detroit mine.



A. "ROLL" IN THIN-BEDDED DAKOTA QUARTZITE, STANDARD STOPE, DETROIT MINE.



B. GALENA ALTERING TO CERUSITE, DETROIT MINE.

the course of the vein was marked by a tough seam of gouge, but it was by no means certain that the gouge is younger than the ore.

If the writer is correct in believing that the Great Northern fault zone intersects the Country Boy vein a few hundred feet to the southwest, the ore of the Country Boy probably bears the same relation to this ore channel as the ore shoots of the Wellington mine. Prospecting east of the present ore shoot would be unlikely to find an extension of the ore if it behaves like the veins of the Wellington mine.

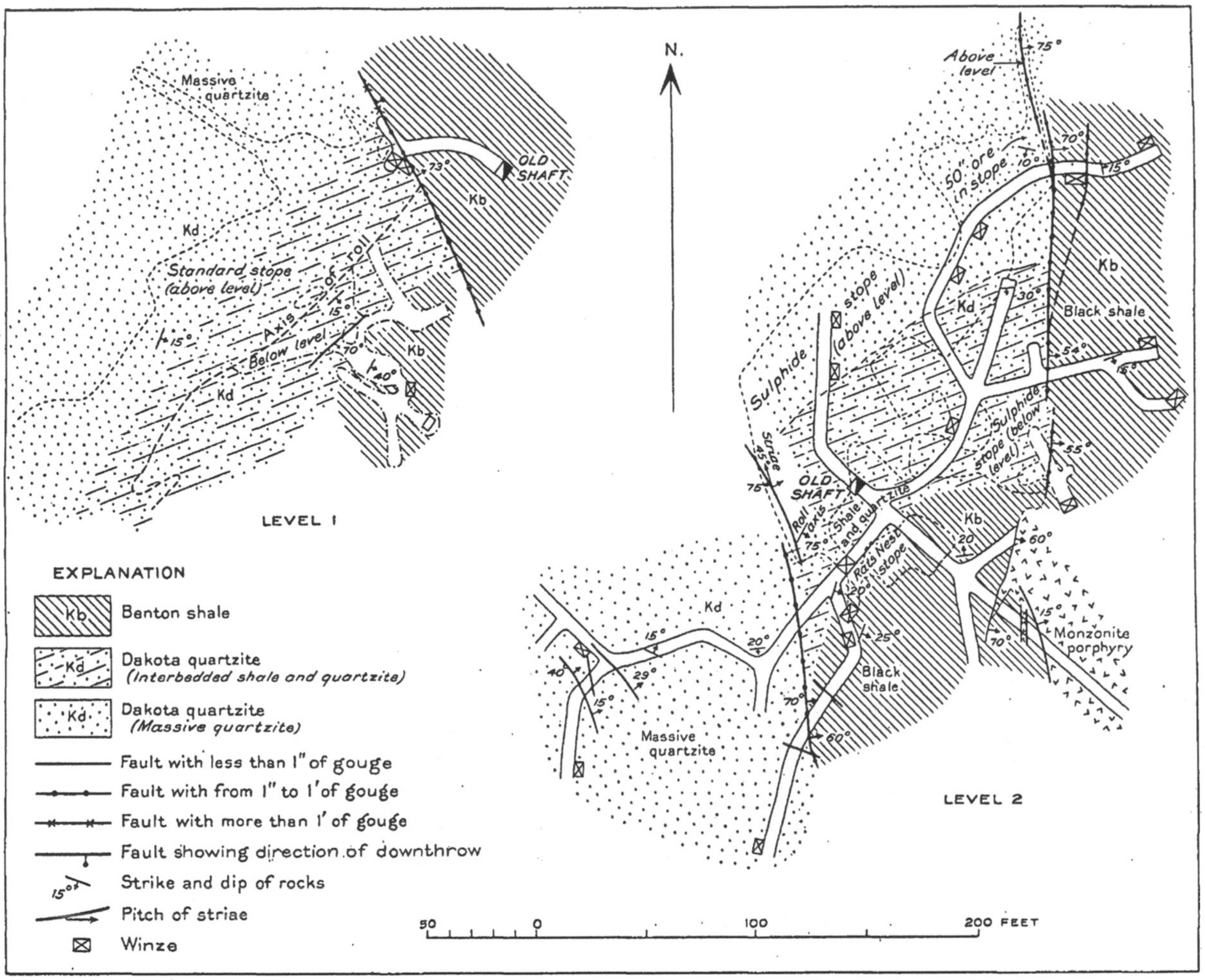


FIGURE 7.—Geology of Detroit mine.

DETROIT

General features.—The Detroit mine lies 1¼ miles northeast of Breckenridge and about 1,000 feet east of the summit of Gibson Hill. It is at an altitude of 10,325 feet and is accessible by means of an automobile road of moderate grade. The mine was first worked about 40 years ago, when rich gold ore was taken from a bedding-plane deposit through an inclined shaft. Accurate data on the early production are lacking. After a long period of idleness the mine was reopened by George Robinson, of Breckenridge, in 1923. A vertical shaft was sunk 151 feet, and three levels were turned. Lead ore carrying considerable gold and silver was found, and since 1924 many shipments have been made. The known production of the mine is given in the table on page 60.

The mine is opened by two vertical shafts—the "old shaft", 151 feet deep, connecting with the productive stopes, and the "new shaft", 80 feet deep, which has been sunk to develop possible ore bodies to the southwest of the "old shaft." Levels have been turned at 40, 90, and 140 feet from the "old shaft" and are shown in figure 6. The drifts from this shaft aggregate about 2,000 feet. In 1928 the underground work was done by hand, and mining was confined to the first and second levels. The ore was sorted and raised to the surface by a steam hoist and placed in appropriate bins. High-grade ore was hauled to Breckenridge for shipment, and low-grade ore was taken to the Extension mill, about a mile to the north. The mill treated about 25 tons of ore a day, producing a high-grade lead concentrate on tables and gold and silver bullion from cyanide treatment of the tails. In 1928 the mill superintendent reported that 80 percent of the gold and 70 percent of the silver were recovered.

Geology.—The Detroit mine is exploiting some of the bedding-plane deposits or blanket veins that are characteristic of Gibson Hill. (See fig. 7.) These deposits occur in replaceable beds of the upper member of the Dakota quartzite. The "old shaft" exposed the following section:

Section in "old shaft" at Detroit mine

	Feet
Wash	3
Benton shale:	
Light-gray shale	56
Jet-black shale	15
Dakota quartzite:	
Black shale interbedded with thin layers of quartzite; shale and quartzite beds ranging from 6 inches to 2 feet in thickness; quartzite becoming more and more prominent toward the base	18
Massive white quartzite; gray to white on fresh fracture but heavily stained with iron on joints	59

The general dip of the sediments near the Detroit mine is about 20° SE. Locally sharp monoclinal folds cause steep dips, and near porphyry masses the beds may be much disturbed. About 100 feet east of the "old shaft" a wide dike of altered monzonite porphyry cuts through the sediments. There are many small irregular offshoots from this mass, and two that were found underground dip about 65° E.

Many small normal faults occur and either parallel the bedding planes of the shaly quartzite or cut across them at low angles. At several places the faults cut through the top of a steep monoclinal fold and produce open broken ground very favorable for the localization of ore. As shown in figures 8 and 9, the weak shaly beds are dragged and crumpled near the intersection of the fault and the fold, resulting in a structure known to miners as a "roll."

The gently dipping faults are cut by a system of steeply dipping normal faults that trend from north to northeast and dip 55°–80° E. or NE.

Ore deposits.—On the first level the Standard stope extends southwest for a distance of about 200 feet and has an average width of 60 feet. The hanging wall of the Standard stope is thin-bedded shaly quartzite, and the footwall or floor is a layer of massive quartzite. The ore occurs in gouge seams of bedding-plane faults and as invisible impregnations in shale and shaly quartzite and can be delimited only by careful sampling. The best and thickest ore coincides with the axis of a "shale roll", where the distance between the floor and back of the stope is 10 feet. (See pl. 8, *A*.) As the ore is followed downward to the northeast, it becomes confined to narrow zones near some bedding-plane faults, which gradually diverge from the gently dipping fault that forms the floor of the stope under the "shale roll." To the northwest the ore decreases in thickness as the faults forming the floor and back of the stope approach each other. Nearly all of the ore from this stope was oxidized, but some sulphides, chiefly galena, were found in its deeper parts. Partly oxidized ore from this stope is shown in plate 8, *B*. A strong northwest fault forms the northeastern limit of the stope and drops the ore-bearing beds to the second level.

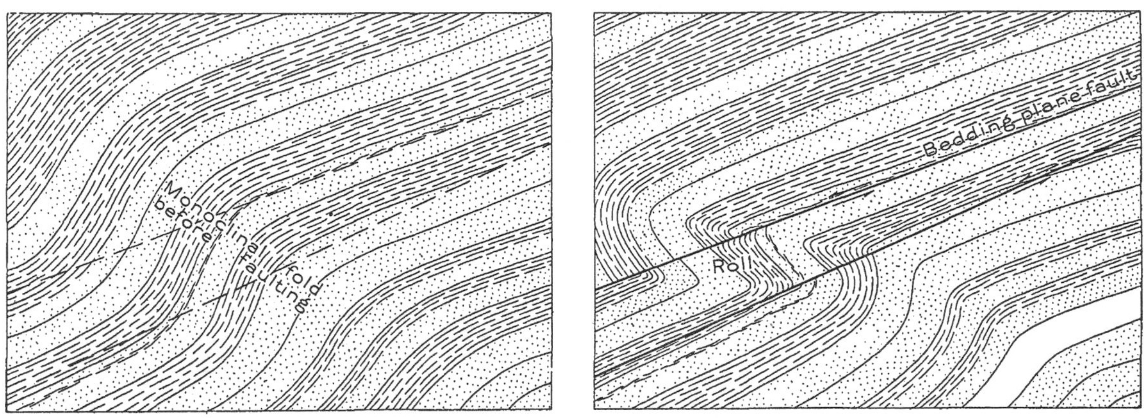


FIGURE 8.—Development of "roll" in Detroit mine through bedding-plane faults.

The conspicuous bedding-plane faults are marked by seams of white, gray, or brown claylike material from 2 to 6 inches thick. According to the miners, the color of the gouge is a guide to the tenor of the seam.

Brown "mud seams" will nearly always assay 2 ounces of gold to the ton; gray "mud seams" vary in value, but usually carry at least 1 ounce of gold to the ton;

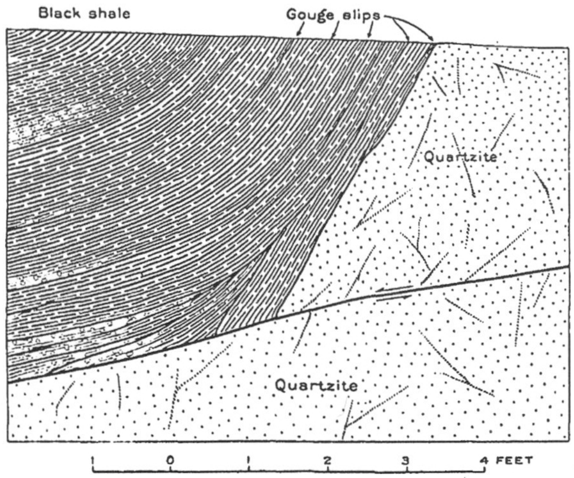


FIGURE 9.—Detail of "roll" in Detroit mine.

the white "mud seams" are the most uncertain and range from half an ounce to 2 ounces of gold to the ton. The small masses of sulphide found in the Standard stope were commonly embedded in gray or brown gouge, and many masses of galena were discovered that were coated with wire silver on the upper surface and with fine-grained gold on the lower surface.

It had replaced black sandy shale between two layers of quartzite about 4 feet apart. In some places the shale was entirely replaced by galena, and 4½ feet of solid ore was mined from the best parts of the stope. The stope is limited on the east by a northward-trending fault, beyond which no commercial ore has been found. A raise was put up from the third level to test the ground east of the fault, in the hope that a faulted continuation of the ore would be found below the second level, but nothing of value was found.

About 15 feet above the Sulphide stope a thin seam of high-grade ore has been stoped. The ore is chiefly galena but contains some sphalerite and pyrite. It lies beneath a thin bedding-plane slip in black shale and is from 3 inches to 1 foot in thickness. (See fig. 10.) A few steeply dipping seams of lead-zinc ore have been found in the masses of porphyry cut 100 feet southwest of the shaft. The seams were narrow, and no attempt was made to follow them.

DUNKIN

The Dunkin mine lies on the southeast side of Nigger Hill about 1½ miles northeast of Breckenridge. It has been worked intermittently since about 1895, has produced oxidized lead ore carrying considerable amounts of gold, and is best known for the shoots of crystallized gold found on the bottom level. The mine was orig-

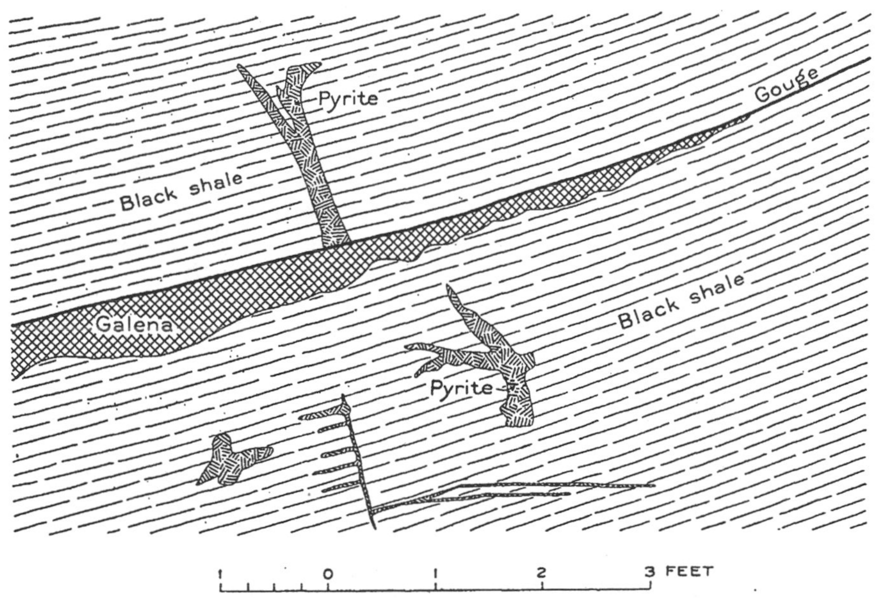


FIGURE 10.—Galena ore in shale, Detroit mine.

On the second level ore has been found at two horizons northeast of the fault that cuts off the Standard stope on the first level. The largest ore body was found in the Sulphide stope and is thought to be the unoxidized equivalent of the Standard stope ore body.

inally opened by the Dunkin Mining Co. with the expectation of developing large bodies of milling ore. After about 7 years of development work, in which little attempt was made to stope and ship ore, the mine was leased to a Mr. Gallager, who drove most of the

Gallager tunnel (see fig. 11) and stoped the ore above it in 1902 to 1906. T. H. Knorr leased the mine from 1906 until 1916 and exploited the mixed sulphide-carbonate ore found below the Gallager tunnel. The high-grade gold ore found in the lowest adit was shipped in 1914 and 1915, and since that time little work has been done on the property. In 1928 George Robinson was reopening the intermediate, or Railroad tunnel, with the hope of reworking some of the old ore shoots and discovering new ore bodies.

The underground workings consist of three main adits—the Gallager tunnel, the Railroad tunnel, and the Redwing tunnel—driven northeastward into Nigger sill that forms much of Nigger Hill, the vein becoming nearly barren soon after it passes into the underlying Benton shale on the Redwing tunnel level. The vein occupies a fault fissure of small vertical displacement that trends northeast in the mine but swings east a short distance beyond the northeast end lines of the Redwing claim. The dip of the vein shows many minor irregularities but does not depart much from an average of 57° SE.

The ore in the Dunkin mine occurred in several lenticular ore shoots separated by barren ground, in which the vein pinched to a tight, narrow seam of gouge. The ore shoots were 50 to 100 feet in breadth

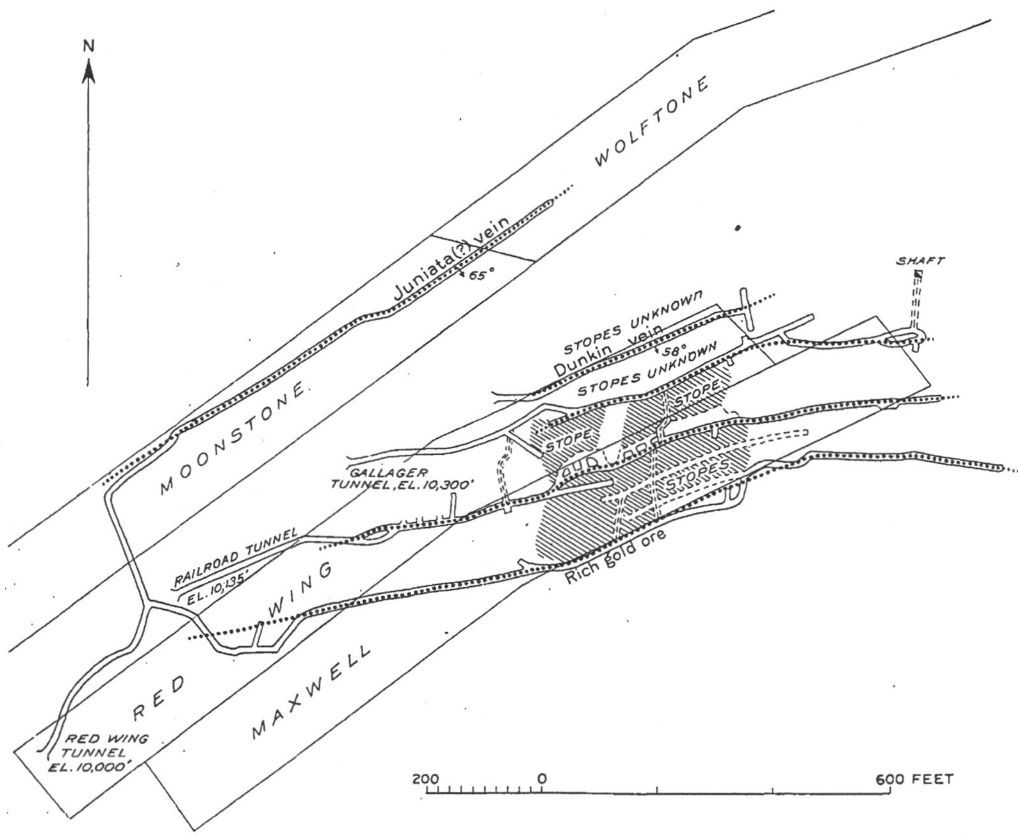


FIGURE 11.—Map of Dunkin mine.

Hill and a few short exploratory openings long since inaccessible. The portal of the Railroad tunnel is on the Colorado & Southern narrow-gage railroad at an altitude of about 10,135 feet. The Gallager tunnel is about 165 feet vertically above it, and the Redwing tunnel is about 135 feet below it. These adits are connected by raises, but the portals of the upper and lower adits were caved in 1928, and only the Railroad tunnel could be entered.

The productive portion of the Dunkin vein lies almost wholly within the thick monzonite porphyry and 200 to 500 feet in pitch length, but only one of them is known to have extended continuously from the bottom level to the surface. The shoots are said to pitch at about 60°–70° NE. The width of the ore in the shoots ranged from 6 to 40 inches between the porphyry walls but narrowed to a few inches where the vein passed into shale, and the vein became a narrow barren seam of quartz and pyrite 15 or 20 feet below the porphyry sill.

The ore in the upper levels consisted almost entirely of cerusite carrying about 1 ounce of gold and 12 ounces of silver to the ton. Below the Railroad tunnel galena and some anglesite were found in addition to the cerusite, which was a notable constituent of all the lead ore mined. No record was made of the zinc in the ore, but it was invariably below 8 percent, as no shipment was ever penalized for its zinc content. Pyrite was found only on the Redwing tunnel level associated with the rich gold ore in the fetid limy shales of the upper Benton beds. The gangue was chiefly sugary iron-stained quartz, according to Mr. Knorr, and the writer found some brown jasper and jarosite in the Railroad tunnel, but no ankerite was observed. Some gold was associated with the jarosite and galena and occurred as small flakes disseminated through the ore.

At the bottom of the long ore shoot that extended from the surface to the Redwing tunnel a rich seam of gold was found. This ore shoot, which is the one farthest from the portal, has a stope length of about 100 feet on the bottom level. Throughout this distance gold was found in paying quantities, commonly in spectacular spongy masses of coarsely crystalline gold from 1 to 4 inches thick and as much as 40 inches in length and height. Some of these pockets netted $10,000 to $35,000 in a few hours, according to Mr. Knorr. A specimen of this high-grade ore shown to the writer was about 2½ inches thick and consisted of a well-crystallized slightly vuggy mass of gold, free from other minerals. White gouge on one side of the specimen and black manganese-stained gouge on the other suggested that it represented the width of the vein at the place where it was obtained. Octahedral faces were prominently developed on the gold crystals, and stout columns of twinned crystals rose from the vuggy openings. Some of the gold is said to have been associated with cubes of pyrite and some of it with galena.

The small vertical displacement on the Dunkin fault vein did not displace the shale-porphyry contact more than 10 feet at any place where it was explored, according to the miners. The report that a shale footwall and a porphyry hanging wall would give way to a porphyry footwall and shale hanging wall suggests that the irregular contact of the sill and shale was moved farther horizontally than vertically. The rich gold ore was practically confined to the upper 10 feet of shale and was best developed where the shale and porphyry overlapped each other on different sides of the vein. (See fig. 12.) The oxidized nature of the ore and the structural relations of the rich gold ore shoot to the shale indicate that it was formed by enrichment through the agency of surface water. For this reason a downward extension of the high-grade gold ore would not be probable. The horizon at which the free gold occurs is nearly 300 feet above the Dakota quartzite, and it is problematic whether the Dunkin vein persists through the thick layer of shale. If there was a large horizontal movement along the vein it is likely that the fissure continues into the quartzite, but if the horizontal component was small the vein probably dies out before reaching the quartzite.

According to Mr. Page, the Redwing tunnel was driven in large part on a fissure parallel to the Dunkin vein, and the ore shoot was discovered by driving a crosscut to it. Thus it is possible that other concentrations of gold ore exist in the unexplored vein between the first and last ore shoots. However, as most of the information on the Dunkin mine was obtained from others, the writer does not feel qualified to offer definite opinions.

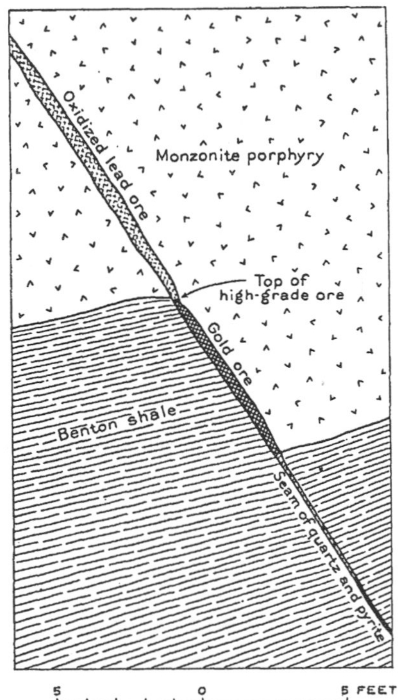


FIGURE 12.—Occurrence of rich gold ore in Dunkin mine.

The western branch of the Redwing tunnel, according to Mr. Knorr, explored a vein containing from 1 to 3 feet of "mill ore" that contained some lead, zinc, and iron sulphide. Its strike and dip suggest that it is a continuation of the Juniata vein.

JUNIATA

The Juniata vein is on Nigger Hill about 1¼ miles east of Breckenridge. Most of the workings are on the north slope of the hill a short distance west of the head of Nigger Gulch. In 1890 the Dunkin Mining Co. owned the Wolftone claim and commenced development work on the Juniata vein within its end lines. The Wolftone shaft was sunk and two levels turned from it, as shown in plate 9. Unfortunately, the vein turns sharply as it enters the Wolftone claim, and in a lawsuit between the Juniata and Dunkin mining companies it was shown that the extralateral rights of the Juniata claim gave its possessor the ownership of nearly all the vein under the Wolftone claim that had been opened by the Dunkin Mining Co. Since the settlement of this lawsuit in 1895 little work has been done.

As shown in plate 9, the vein is opened by several shafts and two adits, one on each side of Nigger Gulch. The Juniata main shaft, an incline said to be about 280 feet deep, and the Wolftone shaft, said to be about 250 feet deep, are the principal shafts on the vein. The 4 levels on the Juniata and the 2 levels on the Wolftone were all inaccessible in 1928, and the available information on the mine is necessarily meager.

The Juniata vein is wholly within porphyry, so far as known, and strikes from N. 50 E. on the Wolftone claim to N. 80 E. on the Juniata claim and dips about 59° SW. The ore was chiefly a high-grade galena-cerusite ore having galena as the most abundant constituent. It is said to have carried more silver than gold in the Wolftone workings, but gold contributed greatly to the value of the ore shipped by the Juniata Co. The galena on the lower levels contained a small amount of sphalerite and pyrite, but there was still a decided preponderance of lead. The vein is said to have pinched to a width of about 4 inches on the third level of the Juniata and is not certainly recognized on the fourth level.

MINES ON LITTLE MOUNTAIN

GERMANIA

The Germania vein is about a mile south of Breckenridge, on the east side of Little Mountain, about 250 yards west of the portal of the Willard tunnel. No map of the underground workings on this vein could be found, but according to reliable information the Germania shaft was 300 feet deep and three productive levels were turned from it. These levels are said to have followed the vein closely, and very few crosscuts were driven to explore the country to the northwest or southeast of the vein. Most of the ore, which was a high-grade lead-silver and gold ore, is said to have come from a large stope 160 feet long and 80 feet wide on the second level.

Geology.—The bottom of the shaft is said to be in red shale, but most of the workings were in quartzite. The black shaly quartzite of the upper part of the Dakota formation crops out a short distance from the shaft, and most of the dump is made up of quartzite. The vein strikes N. 40° E. and dips 80° SE. It is nearly parallel to the large fault 350 feet northwest of the Germania shaft, which has dropped the region to the east a distance of several hundred feet. Southeast of the Germania vein the rocks are influenced by the Rocky Point syncline and dip southeast. The intermediate quartz monzonite porphyry at the south end of Little Mountain sent several fingers into the Germania ground, but so far as could be learned little porphyry was encountered in mining.

There are several prospects and abandoned mines on Little Mountain, and oxidized gold-silver ore was found in small pockets in many of them. The description of the Germania tunnel given below is quoted at length from Ransome's report because it adequately describes a deposit typical of the occurrence of the gold-silver ores of Little Mountain, and the writer does not believe that anything will be gained by the enumeration and description of the other occurrences of ore.

Germania tunnel.—The Germania tunnel was driven with the hope of finding the Germania vein on the west slope of Little Mountain. It enters the hill a short distance above the Blue River, about 20 feet below the level of the Hoosier Pass highway. It was inaccessible at the time of the writer's visit, but, according to Ransome,[70] it

> runs northeast for about 300 feet through boulder till and then through about 140 feet of much disturbed black shale, quartzite, and monzonite porphyry. The structure of these rocks cannot be determined from the present exposures in the tunnel. From the main tunnel a drift turns north on a strong zone of fissuring which dips about 55° W. The rocks along this fissure are crushed and exposures in the drift give no hint of their general structure. At the winze (see fig. 13) a seam of ore was found in hard massive quartzite which was stoped up an incline, as shown. This ore is said to have been of good grade, but the body evidently was small. Its general dip was to the south at about 28°, whereas the dip of the quartzite is about 40°. The quartzite has been irregularly fractured along a plane lying at a little lower angle than the bedding, and the small fissures and interstitial spaces, some of them enlarged by solution, have been coated with quartz druses and are filled with a porous rusty material that is chiefly limonite. This material, which in places carries enough gold and silver to constitute rich ore, is probably an oxidation product of pyrite.
>
> The richest bunch of ore ever found in the quartzite of Little Mountain lay within 10 feet of the surface in the footwall of the strong fissure which is cut in the Germania tunnel and on whose hanging-wall side was the pay shoot that has just been described. A little flat seam of limonite that was followed into the footwall of this fissure was found to expand into an ore body which turned down to the east with the bedding of the quartzite. (See fig. 14.) This mass was about 20 feet in diameter and up to 6 feet thick. Around its edge the ore graded into spongy limonite of no value. The ore itself differed little from this material in appearance, being a very porous mixture of limonite and silica which carried gold and much silver. The silver was for the most part probably native or in the form of cerargyrite, but Thomas West, who discovered the pocket, reports that there was also some "sulphurets of silver"—possibly argentite. A few feet southeast of the ore body the quartzite is cut by monzonite porphyry; the ore thus accumulated in an angle between the fissure and the porphyry.

[70] Ransome, F. L., op. cit., pp. 161-163.

PUZZLE AND GOLDDUST

Puzzle-Ouray vein.—The Puzzle-Ouray vein is about a mile southeast of Breckenridge. It was opened about 1885 and was productive from about 1888 to 1900. Since that time intermittent production has been made by lessees but has not been large. About 1890 the Puzzle and Ouray mining companies became involved in a lawsuit over the ownership of the vein. This suit tested the Puzzle vein 65 feet below that level, and the ground to the northwest has been explored from the Willard tunnel through a crosscut that connects it to the Golddust shaft on the Golddust vein. Ransome estimates the total production of the Puzzle-Ouray vein prior to 1909 at $960,000.

The Willard tunnel level is the principal level of the Puzzle mine as well as of the Golddust mine. The

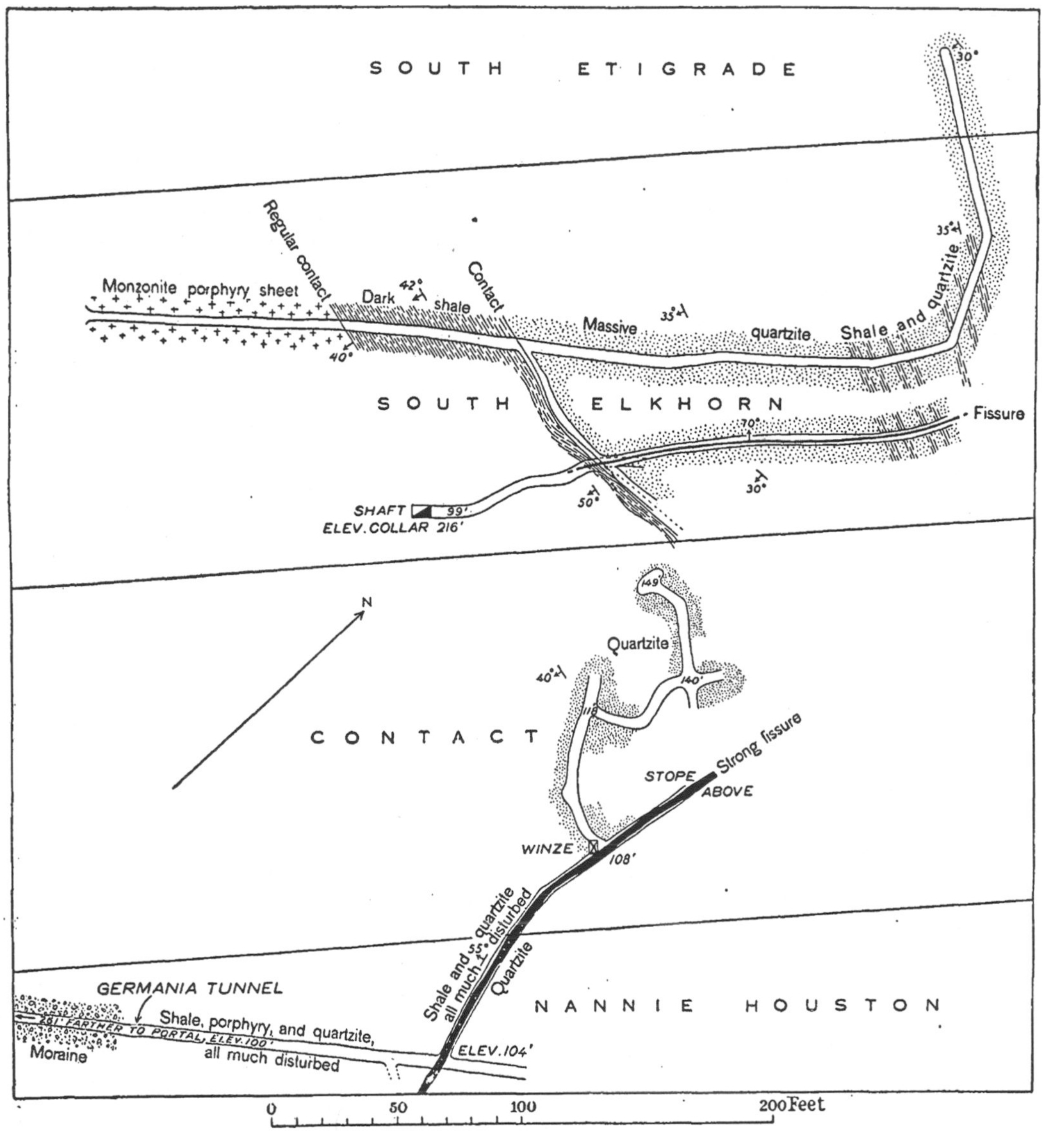


FIGURE 13.—Plan of the Germania and South Elkhorn tunnels in Little Mountain. After Ransome.

was settled in favor of the Puzzle Mining Co. in 1897, and no further work was done on the Ouray claim after that year. Most of the work since 1900 has been of an exploratory nature. A crosscut to the southeast on the second level of the Puzzle Extension shaft was intended to test the Washington vein but was discontinued before it reached its objective; a winze (at *A–A′*, pl. 10, A) sunk from the Willard tunnel level in 1927 portal is directly east of Little Mountain at an altitude of about 9,840 feet, and is a quarter of a mile north of the "horseshoe"—the 350° curve in the railroad below Rocky Point. The tunnel runs 715 feet southeast to the Puzzle vein and turns northeast on the vein, which it follows to the Puzzle Extension shaft. At this point a crosscut connects it with the Golddust shaft and the Pacific vein, as shown in plate 10. The second level, about 95 feet above the Willard level, is open near the Puzzle Extension shaft, and the Sauer's crosscut on this level extends 700 feet southeast of the Puzzle vein and was in good condition in 1928. The rest of the upper levels of the Puzzle, all the Ouray workings, and all the upper workings of the Golddust were inaccessible during the writer's visit. Most of the workings are shallow, and very little production came from the ground below the Willard tunnel, which is only 280 feet below the surface at its deepest point. The Ouray shaft, however, is said to extend 268 feet below the Willard tunnel level, but the section in plate 12 indicates that most of the work in this part of the vein was also confined to a zone less than 280 feet from the surface.

The surface geology is shown in plate 2 and the underground geology in plate 10. As shown in plate 2, the predominant country rock of the Puzzle vein at the surface is Dakota quartzite. The vein cuts diagonally across a local anticline that has a steep south-

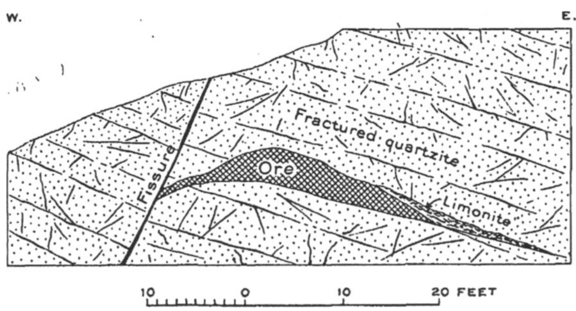


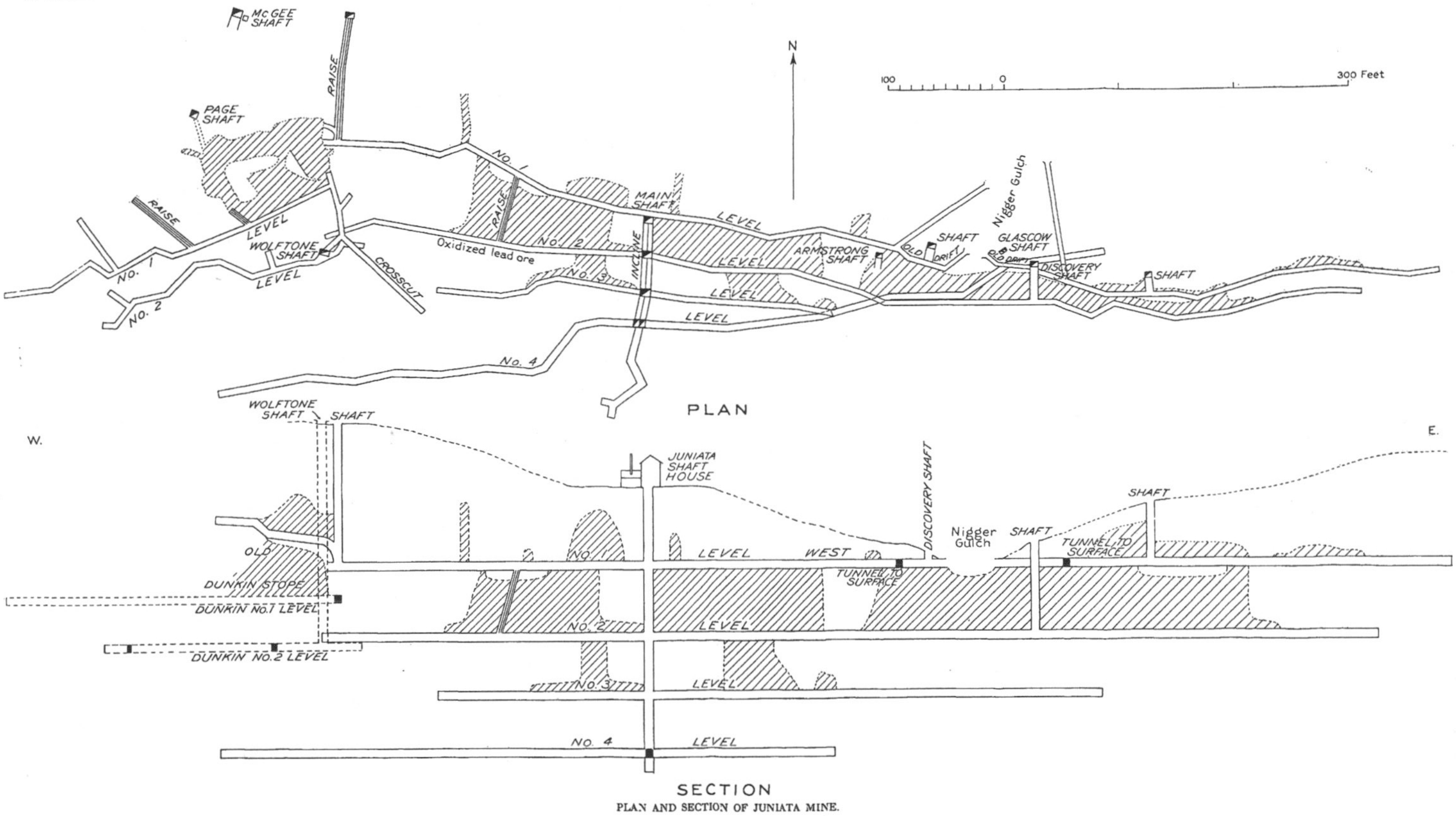
FIGURE 14.—Cross section showing mode of occurrence of a rich pocket of oxidized gold-silver ore in the quartzite of Little Mountain. After Ransome.

east limb and a gently dipping northwest limb. The Benton shale is prominent near the mouth of the Willard tunnel but is not cut by the vein in the workings now accessible, although it is almost certainly present in the old Ouray workings at the southwest end of the vein. The black Benton shale found at the portal of the Willard tunnel is faulted against Dakota quartzite along the Eva vein 165 feet from the entrance. At 295 feet the quartzite is overlain by a sill of monzonite porphyry, and this rock is faulted against the lower part of the Dakota formation 375 feet from the portal. The black shale found at 475 feet overlies a coarse-grained gritty quartzite or arkose, which is probably the basal member of the Dakota formation. Below it a few thin beds of quartzite interstratified with gray calcareous shale suggest a gradual transition to the Morrison formation. Gray shale forms both walls of the Puzzle vein where it is cut by the Willard crosscut and continues on both sides of the drift for 225 feet, where a thick monzonite porphyry sill appears abruptly in the footwall on the northwest side of the drift. From this point to the end of the drift on the Puzzle vein, a distance of 700 feet, the gray shale of the Morrison forms the country rock southeast of the vein and the monzonite porphyry sill forms the northwest wall of the vein. A 20-foot winze at the junction of the vein and the Willard crosscut showed no ore but revealed a bed of quartzite under gray shale and faulted against the gray shale that underlies black shale. The presence of interbedded quartzite, black shale, and gray shale is well shown near the Puzzle Extension shaft and is indicated in plate 10. At a point 375 feet southwest of the shaft a winze was sunk to a depth of 65 feet in 1927. The vein contained a small amount of sphalerite, and gold was reported in a sample obtained at the collar of the winze. The vein, which was nearly vertical here, dipped out of the winze to the northwest about 30 feet below the collar but was found on the sublevel by a short crosscut to the north.

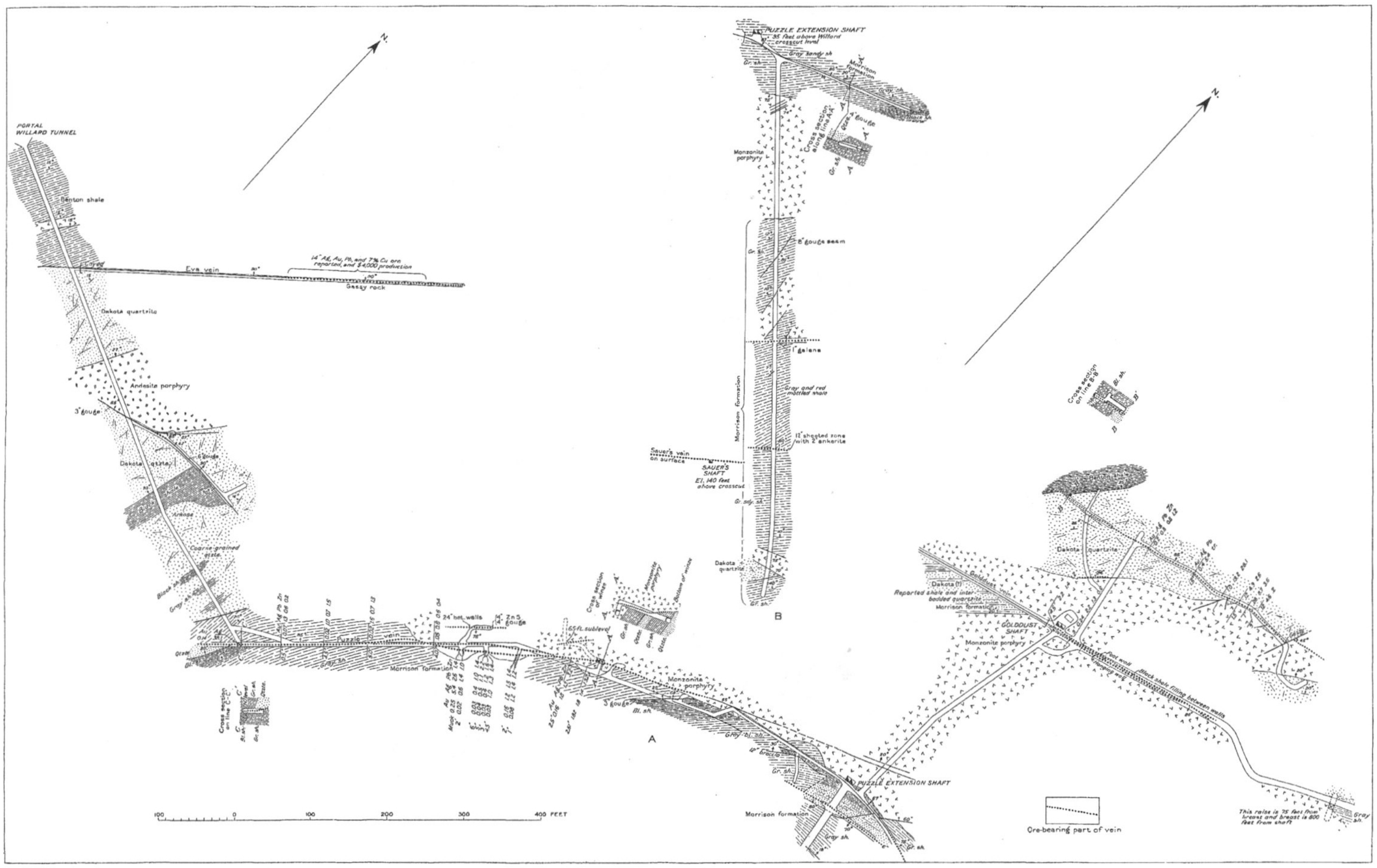
The general course of the Puzzle vein is N. 50°–70° E., and above the Willard tunnel level it dips about 80° N. The pronounced drag of the beds observed in the open cuts on the surface, shown in plate 11, *A*, clearly indicates that the vein occupies a normal fault. The original displacement of this fault was probably about 120 feet, but the intrusion of the porphyry sill on the hanging-wall side has raised the overlying beds and decreased the initial displacement by varying amounts, dependent on the thickness of the sill. According to the miners thin porphyry sills were also found in the footwall of the vein. Locally the porphyry has cut through the fault, but in general it followed the fault plane very closely.

Profitable ore was found only where one or both walls of the vein were quartzite or porphyry. The gray shale of the Morrison underlying the Dakota formation apparently causes a marked decrease in the value of the ore. The relation of the ore to the surface has already been commented on and is well shown in the stope map of the Puzzle-Ouray vein (pl. 12). The relation to the surface suggests enrichment. In a fissure cutting the Morrison and Dakota formations the movement of ground water would be largely confined to the more open fractures above the Morrison, and as enrichment is dependent on the movement of ground water, the double relation of the ore to the surface and the wall rocks can be satisfactorily accounted for by assuming the ore to be secondary. However, primary ore is also localized in open fissures and shows a marked relation to the character of the wall rock. The superior hardness of the quartzite makes it resistant to erosion and relates the surface to it through the very qualities that would localize a primary ore shoot between walls of this formation. The ore seen by the writer was a mixture of galena, zinc blende, and pyrite, which suggested primary and not secondary metallization.

The material shipped from the Puzzle-Ouray vein is reported to have been largely a lead ore carrying moderate amounts of silver, some iron, and less than 8 per-

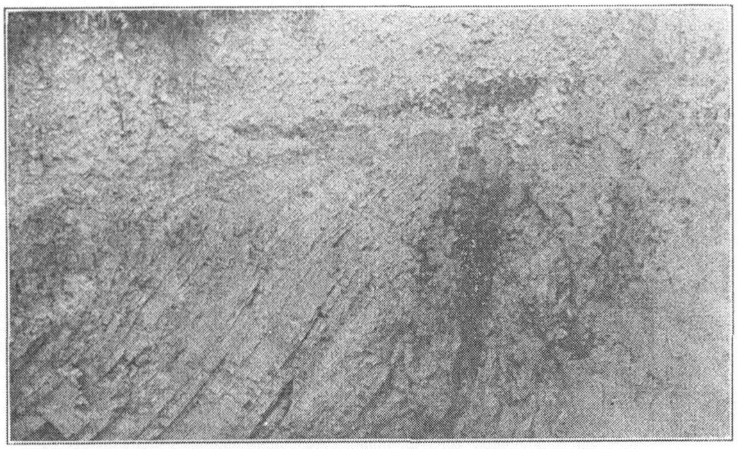


PLAN AND SECTION OF JUNIATA MINE.

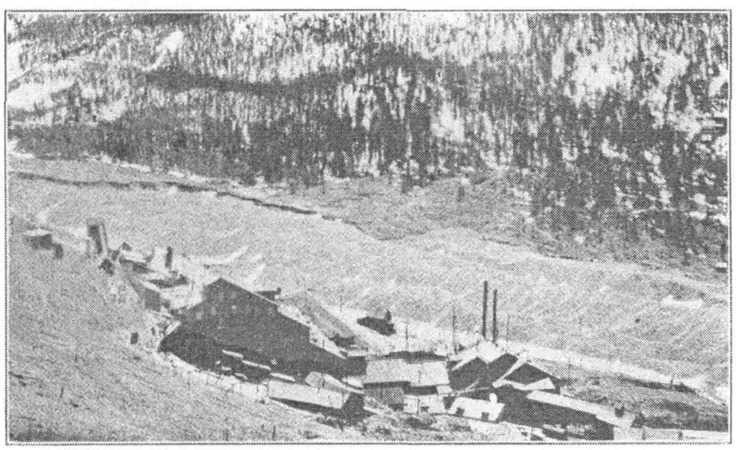


GEOLOGIC AND ASSAY MAP OF PUZZLE, GOLDDUST, AND PACIFIC VEINS.

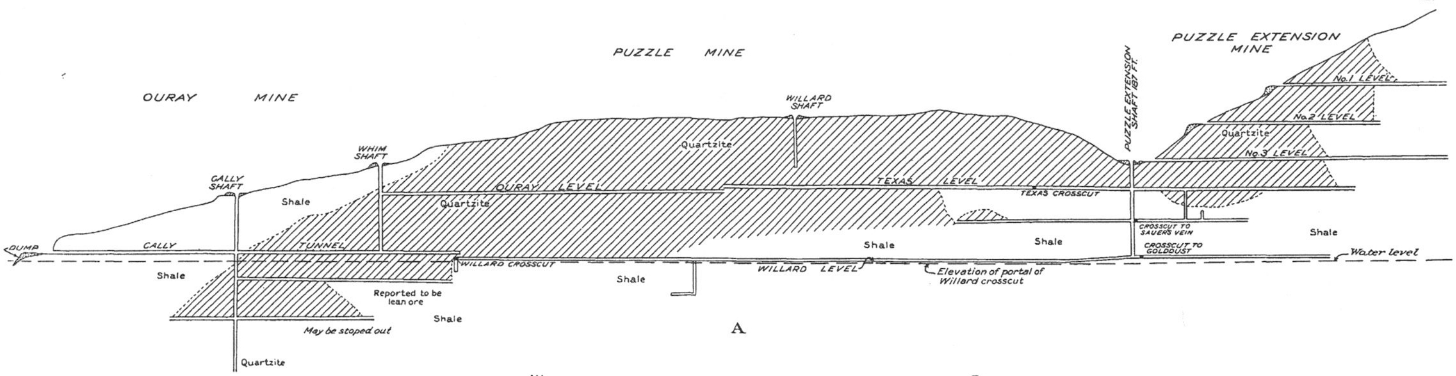
A, Willard tunnel level; B, Sauer's crosscut level.



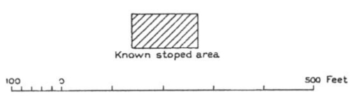
A. OPEN STOPE ON PUZZLE VEIN, LOOKING NORTHEAST.

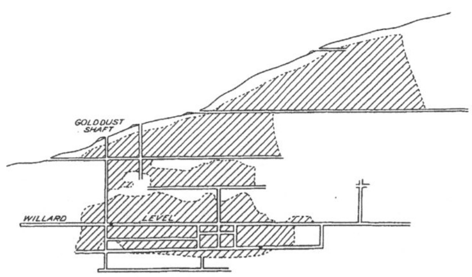


B. WELLINGTON MILLS AND MINE IN 1923.



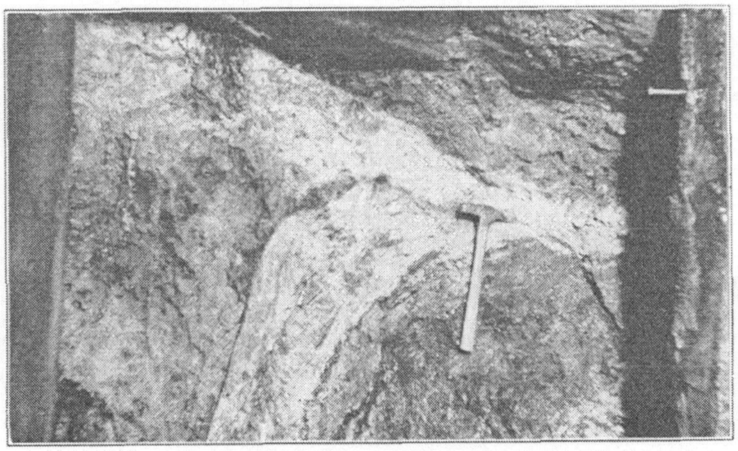
A





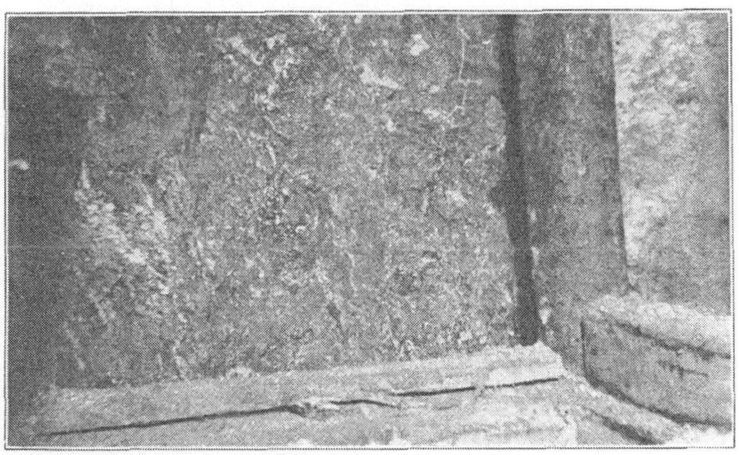
B

STOPE MAPS OF PUZZLE (A) AND GOLDDUST (B) VEINS.



A. MAIN VEIN, WELLINGTON MINE.

Parallel to intrusive contact of cross-breaking monzonite porphyry cut by gently dipping normal fault. (See fig. 18.)



B. PARTIAL REPLACEMENT OF SHALE WALL OF MAIN VEIN, WELLINGTON MINE.

cent of zinc. On the upper levels anglesite and cerusite occurred, but, in general, galena made up the bulk of the material mined at a profit. The vein is said to have been from 1 to 15 feet wide, and although no ore remained for study in the productive parts of the vein, the width of the old stopes and the exposures of the lean portions of the vein suggest that it was from 3 to 5 feet wide in most places.

Golddust vein.—The Golddust vein could be entered only from the Willard tunnel at the time of the writer's visit. The bottom of the Golddust shaft was originally at the level of the Willard tunnel, but it was later deepened by lessees, who turned a level at 28 feet in 1915, another level at 52 feet in 1916, and a third at 87 feet in 1928. All the Golddust workings the Puzzle Extension shaft can be followed along the crosscut to the Golddust shaft. It is underlain by gray shale on the 87-foot sublevel and in the eastward extension of the Puzzle drift. The monzonite porphyry sill forming the north wall of the vein at the Golddust shaft is underlain by quartzite on the 52-foot sublevel and is evidently a different sill from that forming the south wall. On the 87-foot sublevel an irregular dike of porphyry follows the sheeted zone and is clearly later than the first movement on the fault but earlier than mineralization. It probably represents the conduit through which the magma rose to form the sills on the higher levels. Subsequent movement along the sheeted zone resulted in local shattering and the displacement of the sills. The

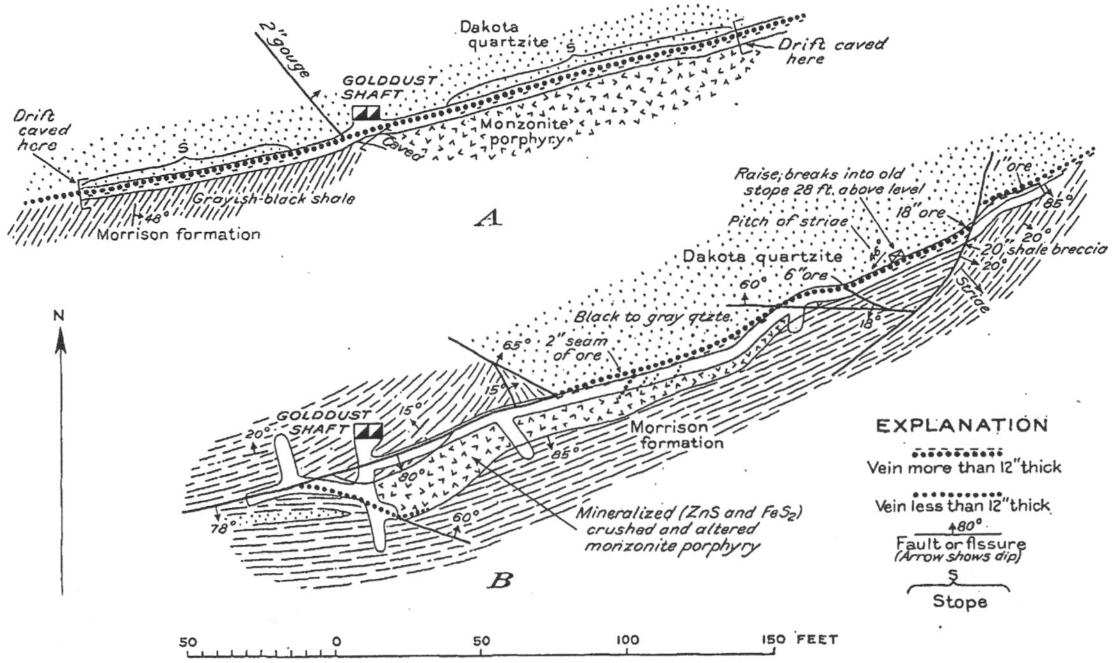


FIGURE 15.—Sublevels of Golddust mine. *A*, 52-foot sublevel; *B*, 87-foot sublevel.

were inaccessible in 1928 except the 87-foot sublevel and a small part of the 52-foot sublevel. (See fig. 15.) The shaft was open to the surface, but the development work was carried on from the Willard tunnel level, where a small underground hoist was installed. A stope map is shown in plate 12.

The Golddust vein is a sheeted zone 15 to 30 feet wide, striking about N. 75° E. and dipping about 80° S. The sheeted zone has fairly definite walls, and the vein matter between them consists of much disturbed and fractured shale, porphyry, and quartzite, replaced in varying degree by galena, pyrite, and sphalerite. This zone was formed by reverse faults.

On the Willard tunnel level at the Golddust shaft monzonite porphyry forms both walls of the vein. The porphyry on the north wall of the Puzzle vein at details of the geology of the 52-foot and 87-foot sublevels are shown in figure 15, and the geology of the Golddust vein on the Willard tunnel level, largely taken from Ransome's report but modified in the light of later developments, is shown in plate 10.

The ore consisted of irregular stringers of sulphides ramifying through the sheeted zone. Usually there was a persistent vein on the hanging wall and the footwall of the sheeted zone. These veins ranged from a few inches to 3 feet in width. In the disturbed rock between the two walls of the sheeted zone the stringers of ore branched and disappeared, or joined and formed a workable seam of ore. According to several miners, the vein was at one place 30 feet wide, and 4 wide seams of ore furnished material for cars on 4 parallel tracks. The sketch of the occurrence of ore shown in figure 16, taken from Ransome's report, illustrates the irregular nature of the seams of ore on this level. On the 52-foot sublevel the ore was more compact and occurred chiefly in a vein on the footwall of the sheeted zone. In places on this sublevel the ore was nearly 4 feet wide and consisted chiefly of galena. On much of this level underhand stopes 10 to 15 feet deep were made. On the 87-foot sublevel no shipping ore was found. The porphyry vein filling was impregnated with thin seams of sphalerite, generally less than 30 inches in length, and galena was disseminated through it in the form of fine grains. On this sublevel a vein of galena and sphalerite from one eighth to 3 inches wide was found on the footwall between quartzite and porphyry walls about 80 feet east of the shaft. The ore extended to the bottom of the drift in only a few places until a point about 165 feet from the shaft was reached. Here

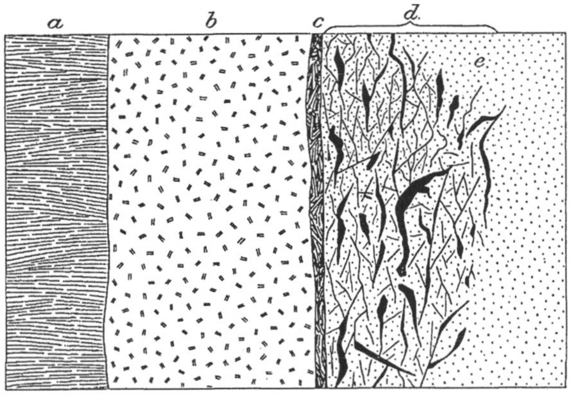


FIGURE 16.—Occurrence of ore in Golddust vein. After Ransome. *a*, Disturbed black shale; *b*, porphyry; *c*, gouge; *d*, ore; *e*, quartzite.

the vein thickened to about 6 inches, and at 200 feet from the shaft it became about 12 inches wide at the top of the drift. A raise upon this ore broke into an underhand stope 28 feet above the level, where the ore had widened to about 2½ feet. Evidently the southwestern part of the ore shoot bottomed very abruptly between the 52-foot and 87-foot sublevels. Although little ore was found on the bottom level, the sheeted zone was very well defined, and the shale, porphyry, and quartzite filling were strongly impregnated with pyrite and to a less extent with sphalerite.

The Golddust ore is reported to have been largely a galena ore, and the record of the shipments from this vein show that the value lay chiefly in lead and to a less extent in silver. Apparently zinc became more abundant in the lower levels, but the shipments from the 52-foot sublevel were not penalized for their zinc content, and it is safe to conclude that sphalerite was only locally an abundant constituent of the Golddust ore.

Pacific vein.—The Pacific vein is parallel to the Golddust vein and lies about 150 feet north of it on the Willard tunnel level. The adits that explored the upper part of the Pacific vein have long been inaccessible. A continuation of the crosscut that connects the Puzzle Extension shaft with the Golddust shaft has been the means of exploring the Pacific vein on the Willard tunnel level. During the summers of 1915–25 lessees stoped and shipped 218½ tons of ore, which averaged about 0.5 ounce of gold and 15 ounces of silver to the ton, 30 percent of lead, and about 13 percent of zinc. A small amount of development work has been done since 1916, but no shipments have been made.

The Pacific vein occupies a small normal fault that dips 85° NW. The fault and the vein abruptly decrease in strength southwest of the Golddust crosscut, most of the movement having been taken up by folding and minor fissuring in the black Benton shale. The quartzite underlying the shale rises to the east, and in this formation the vein is much stronger. The shipping ore came from a small stope in the quartzite immediately under the Benton shale. The monzonite porphyry southeast of the quartzite clearly underlies it and is sill-like in form where it is cut by the Golddust crosscut, but near the east end of the Pacific drift, where the porphyry forms the southeast wall of the Pacific vein, it is in part cross-breaking. The surface geology suggests that this porphyry is part of an irregular pipelike conduit connected with the Nigger Hill sill.

The ore of the Pacific vein taken from the surface workings is reported to have been an oxidized lead-gold ore. The ore from the stope on the Willard tunnel level was entirely a sulphide ore and contained pyrite and sphalerite in sufficient amounts to detract from its value as a lead ore. The vein and its walls were heavily pyritized as far as it had been explored, but galena was confined to the region stoped. The character of the ore and its occurrence below the Benton shale indicate that it is primary and has not been reconcentrated by surface waters.

Washington and Emmet veins.—The Washington mine is 1½ miles southeast of Breckenridge, on the north side of Illinois Gulch. According to Ransome,[71]

This is one of the older mines of the district and as early as 1883 was giving employment to over 30 men. A 20-stamp mill was built about 1885. At this time and for a few years later the mine was worked through the Watson shaft, situated at an elevation of 10,550 feet on the spur connecting Nigger Hill with Bald Mountain. The mine continued steadily productive until 1891, after which it appears to have been turned over to lessees, who made shipments up to 1897 and perhaps later. The total output of the Washington mine, as given in a prospectus issued by the Washington-Joliet Mining & Milling Co., capitalized at $1,500,000, is between $400,000 and $500,000. There is no reason to suppose that this statement is exaggerated.

The underground workings consist of the old shaft on the hill, from which considerable drifting and stoping was done, and of

[71] Ransome, F. L., op. cit., p. 141.

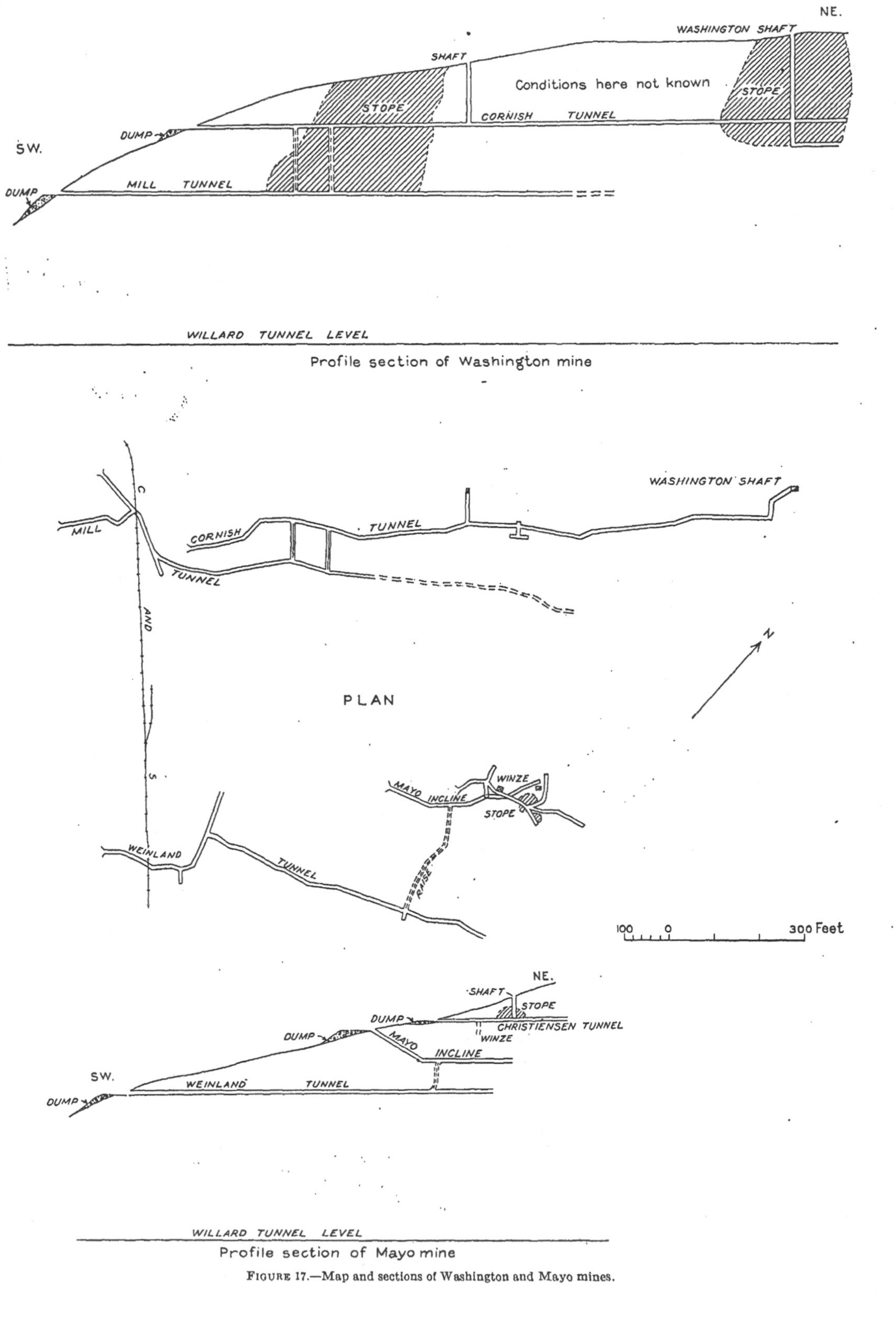


FIGURE 17.—Map and sections of Washington and Mayo mines.

six tunnels on the slope from the shaft down to Illinois Gulch. Of these the most important is the Cornish tunnel, which follows the Washington vein in a general northeast direction for about 1,400 feet and connects with the shaft at a depth of 250 feet. At 115 feet below the Cornish tunnel is the Berlin tunnel, supposed to be on the Emmet, a vein parallel with and a short distance southeast of the Washington.

The Berlin tunnel is also known as the Shonty tunnel and the Mill tunnel. A map and section of the underground workings and the stopes, so far as known, are shown in figure 17. According to John Nelson, the breast of the Berlin tunnel is now about 1,150 feet from the portal. A raise 630 feet from the portal is said to connect the lower adit with the Cornish tunnel. Unfortunately the underground workings of the Washington mine were inaccessible at the time of Ransome's visit and also in 1928, when the writer studied the district.

The Washington vein strikes N. 50° E. and dips about 70° SE. The Emmet vein is a parallel vein from 15 to 20 feet southeast of the Washington vein and may be considered part of the same mineralized fault zone. The Berlin tunnel is said to pass through some red shale near the portal but to traverse porphyry for most of its length. The Cornish tunnel enters the hill in Dakota quartzite but is said to be in porphyry for most of its length, passing into black shale near the shaft. By far the bulk of the material on the dumps of the two adits consists of porphyry. The ore is said to be a lead-silver ore containing small amounts of gold and zinc similar to the ore found in the Puzzle and Golddust veins.

Mayo vein.—The Mayo vein lies about 600 feet southeast of the Washington vein and was opened through the Christensen tunnel, the Mayo incline, and the Weinland tunnel. All the workings were in bad condition at the time of the writer's visit and were not studied underground. A map and section of the Mayo workings are shown in figure 17. The Mayo vein has produced at least $50,000 in lead-silver ore but has not been worked for 30 years.

The Mayo vein trends northeast and dips about 65° SE., but most of the ore was obtained from a "flat vein" striking about N. 75° E. and dipping 25° S. It is probable that the ore found in the "flat vein" was a bedding-plane deposit in the Dakota quartzite, which crops out near the Mayo incline and strikes N. 65° E. and dips 21° S.

Horn vein.—About 300 feet southeast of the Mayo vein is another vein striking N. 25° E. and dipping 75° NW. It was developed through the Horn tunnel, long since caved and inaccessible, and is known to have supplied some good oxidized lead ore containing about 25 ounces of silver and half an ounce of gold to the ton when it was worked by the Washington Mining Co.

WELLINGTON

ACKNOWLEDGMENTS

The well-kept mine records of the Wellington Mines Co. and the intimate personal knowledge of the mine which Mr. R. M. Henderson, the general manager, and Mr. H. L. Tedrow, the mine superintendent, placed at the writer's disposal, made the study of the mine an unusually profitable and pleasurable task. Information furnished by them on inaccessible parts of the mine was indispensable in obtaining the picture of the geology given below. In addition maps and reports of the old workings, made by Mr. John Wellington Finch at various times prior to 1920, were placed in the writer's hands and were invaluable.

HISTORY

The Wellington Mines Co. in 1929 owned the old Oro mine and the original Wellington mine. The Oro mine first became productive about 1887, and the Wellington was opened a short time later; during the period of their separate existence the Oro mine was more productive than the Wellington. Shipments at that time consisted of argentiferous lead ore, made up largely of cerusite and galena. As zinc was then regarded as waste and penalized by the lead smelters, no effort was made to save it. The Wellington and Oro mines were consolidated in 1902 by the Colorado & Wyoming Development Co., but little work was done until the present Wellington Mines Co. took over the property about 5 years later.

A 100-ton gravity concentration mill was built at the mine in 1908, and by the following year 25 tons of galena concentrates and about 10 tons of zinc middlings were being shipped daily. High-grade zinc concentrates and crude lead ore of smelting grade were also shipped from time to time. A 50-ton roaster and magnetic separating mill were built in 1912 to remove the iron from the zinc middlings. The mixed lead-zinc ore of the mine was successfully treated by the two mills until 1927, when the gravity concentration plant was changed into a flotation mill because of the greater economy of its operation. The two mills and the Oro shaft are shown in plate 11, *B*. The roaster and magnetic separation plant have been entirely abandoned since August 1927, when the new mill started work.

Except for a 2-year period of idleness in 1920 and 1921, the mine produced large amounts of both lead and zinc from 1909 to 1929. The production of the property is given in the table on page 62.

DEVELOPMENT

The relations of the levels and shafts are shown in plate 13. The original Wellington mine was opened by several adits, the largest of which was the X-10-U-8, driven north-northwest at an altitude of 10,040 feet.

This adit connects with the collar of an underground inclined shaft from which five levels have been turned. Close to the mill and 1,700 feet S. 35° W. of the inclined shaft, the Oro workings are opened by the vertical Oro shaft. The two shafts are joined by their fifth and sixth levels, but the other levels connect with only one shaft. The deepest level in 1928—the Oro eighth—was not directly connected with the Oro shaft but was opened by a winze near the east end of the seventh level. The altitudes of the levels at the Wellington and Oro shafts and their approximate extent are given below.

	Extent (feet)	Altitude at shaft (feet)
Wellington levels:		
First	8, 090	10, 048
Second	6, 590	9, 962
Third	6, 480	9, 863
Fourth	5, 700	9, 730
Fifth	8, 220	9, 601
Sixth	6, 720	9, 470
Oro tunnel	1, 020	----------
Oro levels:		
First	2, 020	9, 844
Second	1, 320	9, 774
Third	1, 480	9, 715
Fourth	420	9, 637
Fifth	(8, 220)	9, 612
Sixth	(6, 720)	9, 488
Seventh	2, 990	9, 361
Eighth	2, 200	9, 260
Siam tunnel	1, 150	----------
Prize Box tunnel	1, 610	----------
Brown tunnel	1, 410	----------
Other surface workings	9, 150	----------
Drifts and crosscuts, total	66, 570	----------
Shafts	1, 346	----------

Active mining has been confined to the Oro workings for several years, and the Wellington inclined shaft has been used only for the care of the pump station on the sixth level, which handles all the underground water of the mine.

GENERAL GEOLOGY

The surface geology is shown on plate 2 and figure 20. The Wellington Main vein (pl. 14) lies in the downthrown Oro fault block, which is bounded on the west by the Bullhide fault and on the east by the Great Northern-J fault zone. (See fig. 20.) Most of the Oro workings are in this fault block, but the Wellington levels develop ground in both this downthrown

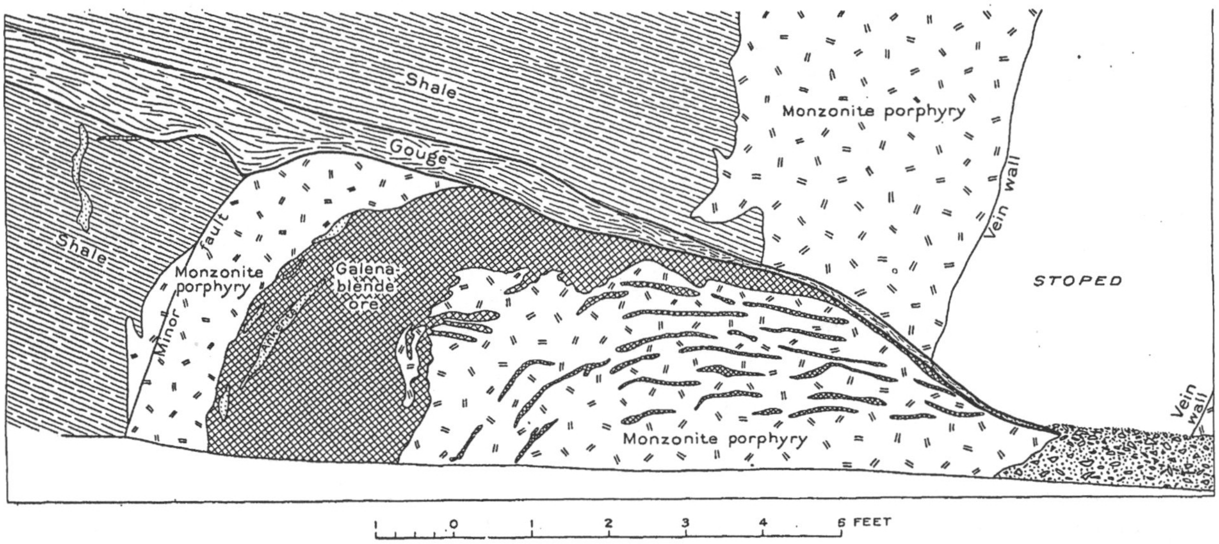


FIGURE 18.—Main vein, Wellington mine, paralleling intrusive contact of cross-breaking monzonite porphyry.

block and in the upthrown Wellington block east of the Great Northern-J fault zone. The upper levels are almost wholly in monzonite porphyry, but the lower levels expose Pierre, Niobrara, Benton, Dakota, and Morrison beds. The monzonite porphyry is part of the northern border of the large irregular intrusive mass that forms much of the upper part of Bald Mountain and was formerly continuous with the porphyry mass of Nigger Hill.

Porphyry is exposed on the surface near the Oro shaft, but Dakota quartzite crops out in a low cliff a few hundred feet farther west, near the small gully where the Bullhide fault comes to the surface. Above the quartzite alternations of shale and porphyry indicate sills of monzonite porphyry in the Benton shale. On the east side of the fault monzonite porphyry is exposed over a wide area and is cut by a dike of coarse-grained quartz monzonite porphyry near the top of the hill. A study of the dredge tailings shows that black shale forms the bedrock east of the Bullhide fault for a thousand feet. Monzonite porphyry next appears, and no more shale is seen until the Great Northern-J fault zone is passed, beyond which shale again appears in the dredgings.

Most of the rock exposed underground is monzonite porphyry. It has been intruded in large irregular bodies which are roughly parallel to the bedding of the sediments but which to some extent follow early faults and break across the bedding, as shown in the geologic sections in plate 15. In places these early planes of weakness were reopened many times, and the Main vein is in part along a fault fissure that follows the cross-breaking intrusive contact of a monzonite porphyry mass. At the place shown in figure 18 monzonite porphyry was intruded along a fault fissure in the sediments, and later movement along the intrusive contact opened channels for ore-bearing solutions. A small gougy fault offset the porphyry and vein before mineralization was completed, and much ore was dragged into the gouge, but some pyrite and ankerite cut through the gouge. It is impossible to work out the exact amount of movement that has occurred on all the many faults found underground or to be sure of the amount of displacement at different points along a major fault. The history is complex, and the adjustments that occurred during faulting before and after the intrusion of the porphyry have been obscured by the disruptions that attended the intrusion. Only the major features of the structure are considered, and many interesting and puzzling details are left unmentioned, but it is hoped that the text, supplemented by the geologic map and sections, will give an adequate picture of the geology.

Most of the intrusive rock is moderately fine grained light-colored monzonite porphyry and does not appear conspicuously porphyritic to the unaided eye. Much of it is bleached and altered, but irregular masses of moderately fresh rock occur in the lower levels. The most common facies of unaltered porphyry is a dark-gray medium-grained rock containing many phenocrysts of biotite. It is locally known as diorite and seems to be richer in ferromagnesian minerals than the large mass of altered monzonite porphyry found in the upper levels. This diorite is abundant near the inclined shaft on the fifth and sixth levels and occurs in small bodies on the Oro seventh level; a diamond-drill core obtained 510 feet east of the Oro shaft shows that a thick mass lies 200 feet below the seventh level.

Gray siliceous shale belonging to the Morrison formation was recognized on the sixth level south of the Wellington shaft. On the same level pink shale, sandy quartzite, and gray shale of Morrison age were also found in the Bullhide fault zone west of the Oro shaft.

Massive light-gray quartzite, thin-bedded shaly quartzite, and gray sandy shale belonging to the Dakota formation occur on the Wellington sixth level, as shown on plate 15, and massive gray quartzite was found on the Oro fifth level west of the Bullhide fault.

Black shale belonging to the Benton is probably present at the west end of the Oro seventh and eighth levels and may occur on the Wellington sixth level, but the stratigraphic relations are not clear in the latter place, and it is generally impossible to distinguish the Benton shale from the Pierre shale lithologically.

The limy Niobrara shales are abundant on the sixth, seventh, and eighth levels of the Oro shaft. The upper member, characterized by numerous veinlets of secondary calcite, is well exposed 100 feet east of the Oro shaft on the sixth level. This horizon is about 650 feet above the Dakota quartzite. The limy shale beds of the Niobrara, which underlie this member for 300 feet, are the only sediments exposed on the seventh level, and the lower part of the formation is well shown near the winze on the eighth level. Much of the limy shale has been strongly silicified near the veins and is converted into black jasperoid, locally called jasper. Ore has replaced favorable beds in the lower part of the formation at several places, but the replaceable beds are generally less than a foot thick, and ore bodies of this type have not proved profitable. The Oro third level is almost entirely in the somber-colored Pierre shale west of the shaft, and the large masses of shale found on the fifth level belong to this formation. The Pierre shale is generally much less silicified near the veins than the Niobrara formation.

STRUCTURE

The chief elements of the structure and the location of the veins and faults referred to below are shown in figure 20. The two strong northerly normal faults, the Bullhide and the Great Northern-J, are the dominant structural features of the mine and limit the downthrown Oro fault block to the west and east respectively. The Bullhide fault, which comes to the surface about 500 feet west of the Oro shaft, strikes N. 26° E. and dips 58° E. The contact of the Pierre shale and Niobrara formation is probably a very short distance below the Oro fifth level, where that level cuts the Bullhide fault. The lower member of the Dakota quartzite is on the west side of the fault on this level, but the exact position of the base of the quartzite is not known. If the base is assumed to be 60 feet below this level, it is very unlikely that an error of more than 50 feet will be made. Under this assumption the top of the Niobrara formation is faulted down to a point about 70 feet below the top of the Dakota quartzite. If there are no sills between the quartzite and the Niobrara shale, the vertical displacement corresponding to such faulting is 790 feet, with a possible error of 50 feet. Until more exact measurements can be made, however, it will be assumed that the throw on the Bullhide fault is approximately 800 feet and that the dip slip is about 900 feet. The quartz monzonite porphyry dike on the upper part of Prospect Hill is offset by the Bullhide fault, the western segment cropping out about 300 feet to the south of the eastern segment. As this dike dips 65°–80° S. in the upper Wellington workings, the offset may be due to the displacement of a southward-dipping mass and cannot be taken as proof of a horizontal component of movement. The bedrock geology revealed by the dredgings west of the Bullhide fault shows that the offset of the southward-dipping Main vein cannot exceed 350 feet and does not indicate a horizontal component of movement along the fault. The displacement given above cannot be taken as general and will be increased or diminished wherever earlier cross faults are cut. As the Main vein follows a fault that has a throw of about 110 feet, the displacement along the Bullhide fault between the offset segments of the vein should be about 900 feet.

The Bullhide fault zone ranges from 5 to 15 feet in width and is characterized by an abundance of gouge and broken quartzite, shale, and porphyry intimately mixed and having little relation to the adjacent walls. Sulphide bunches, ranging in size from those comprising a few cubic feet to bodies large enough to furnish several mine cars of ore, are common in this broken ground. Quartzite fragments are commonly mineralized and partly replaced by pyrite, galena, and sphalerite. Some of the sulphide bunches are massive and unbroken, but many of them are shattered and pulverized by postmineral movement. In places veins of sulphide cut across the gouge and clearly were formed after a large amount of movement had occurred and show that the fault is in part premineral. The postmineral movement was probably confined to one of the walls of the fault, where the veins that cut the gouge appear, and conversely, in the places where shattered bunches of ore are found, postmineral movement affected the entire width of the fault zone.

The Great Northern-J fault zone was traced on the surface by the writer and shows best in the dredge tailings and where it offsets the quartz monzonite porphyry dike, a short distance below the saddle separating Mineral Hill from Prospect Hill. It is regrettable that the condition of the Wellington workings made it impossible to study the fault underground, but, as already noted, this part of the mine was mapped by Mr. John Wellington Finch when conditions were more favorable, and these maps were courteously made available to the writer.

The strong fault zone that forms the western limit of the Great Northern vein is called the Great Northern fault. (See fig. 20 and pl. 15.) It strikes about N. 15° E. and dips approximately 60° W. It is a strong, narrow fault in its southernmost exposures, but to the north it splits into many minor fractures. It is last recognized at a point about 475 feet southeast of the Wellington shaft on the second level, where it shows as a crushed zone in the porphyry about 15 feet wide, dipping 66° W. On the third level, 80 feet to the south, it is much stronger and makes a crushed zone 60 feet wide, limited on the east by a definite fissure that dips 65° W. On the fourth level the movement was taken up chiefly on one strong gouge-filled fissure that strikes N. 10° E. and dips 60° W. The walls of the Great Northern vein were shattered near the fault on this level, and a chamber of ore about 35 feet wide was found. Grooves on the walls of the fault are said to dip steeply to the south. On the sixth and seventh levels the fault is strong and definite and strikes about N. 20° E. and dips 50°–70° W. It is reported that quartzite was found in the footwall on the sixth level and that the hanging wall was made up of black limestone and porphyry. At the eastern end of the Oro seventh level, about 80 feet north of the point where the fault was cut on the sixth level, the drift follows a steeply dipping fault having porphyry on the west and Niobrara limestone on the east. The porphyry is part of a thick sill and is intruded slightly below the top of the Niobrara formation so that the top has been lifted far above its normal position. However, in order to arrive at the general order of magnitude of the Great Northern fault, it is inferred that the upper part of the Niobrara formation is west of the fault on the seventh level and that the lower part of the Dakota quartzite is east of the fault on the sixth level. These relations indicate a vertical displacement of 850 feet, which is comparable to that of the Bullhide fault, but this amount may be in error by 100 feet.

The movement taken up by the Great Northern fault is gradually transferred to a more steeply dipping fault in a wide zone of broken ground a few hundred feet south of the Wellington shaft. (See fig. 20.) North of the shaft the movement is confined to one or two strong faults that strike north to N. 10° E. and dip 65°–85° W. The strongest of the steeply dipping faults is named the J fault, and there is no sharp junction between it and the Great Northern fault. Strong gouge-filled fractures in the much broken ground where the two master faults merge lack continuity both vertically and horizontally. A fault marked by a gouge seam 3 feet wide may not persist 200 feet vertically in this transition zone.

As shown in figure 20, the quartz monzonite porphyry dike west of the J fault, in the upper part of the Wellington workings, is offset about 80 feet to the south of the eastern segment. As the dike dips steeply to the south this offset probably reflects the horizontal component of movement suggested by the grooves noted on the walls of the Great Northern fault. The amount of vertical displacement on the J fault is not known but is probably similar to that on the Great Northern fault.

Many small masses of ore have been found in the Great Northern-J fault zone, and there is a marked increase in the width of the ore in the veins near the faults. Most of the ore within the fault is crushed, showing that postmineral movement has taken place. The increase in strength shown by the veins as they approach the fault zone, however, can hardly be a coincidence and indicates that the vein fissures were opened near the fault by movement along it, before or during mineralization.

In the western part of the Oro fault block an eastward-dipping fracture known as the 11–10 fault has been traced from the surface to the eighth level. (See pl. 15 and fig. 20.) It strikes nearly north and dips 30°–40° E. The throw of the fault is not large and is probably about 50 feet, where the movement is not partly absorbed on minor faults nearby. There is a decided horizontal component of movement, however, and grooves in the walls on the eighth level indicate that here the direction of slip was about 30° south of the direction of dip. The calculated net slip is about 110 feet, and the strike slip is 45 to 50 feet. All the veins west of the fault are 45 to 90 feet farther south on the east side of the fault, the distance depending on their direction and amount of dip. The movement in the lower levels seems to be somewhat less than that

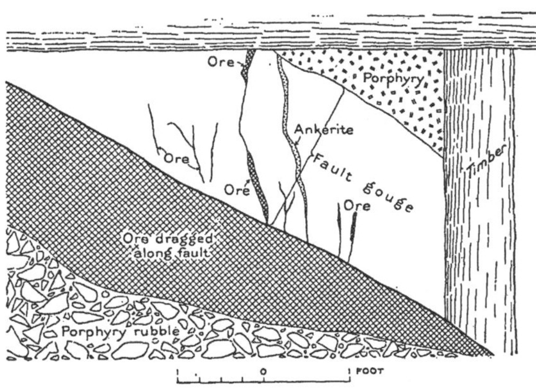


FIGURE 19.—Fault later than Puzzle vein fissure but in part premineral.

in the upper levels and probably foreshadows the disappearance of the fault in depth.

Crushed ore mixed with gouge and the pronounced drag of the ore at the 11-10 fault indicate that considerable postmineral movement has occurred along it. The localization of ore shoots at the junction of the veins and this fault, however, suggests that the fault has determined the position of the ore shoots and that it must be in part premineral. Sulphide veins an inch wide cut the gouge of a minor fault nearby which offsets the Puzzle vein in the same direction as the 11-10 fault, clearly showing that much of the movement on the smaller related faults is premineral. (See fig. 19.)

Where most of the movement has been taken up on a single plane the 11-10 fault is marked by a seam of gouge and breccia 2 or 3 feet wide. In many places, however, it splits and branches, and the movement is distributed on several parallel and branching faults in a zone from 50 to 75 feet wide. In addition to the 11-10 fault and the fractures directly related to it, there are many smaller faults that dip gently to the east in the Oro fault block. They do not warrant detailed consideration but are shown in the cross sections and on the geologic maps of the levels on plate 15. Many of the gently dipping faults pass into bedding-plane slips that soon disappear, and most of them lack persistence in any direction and have no influence on the localization of ore shoots.

VEINS IN THE WELLINGTON FAULT BLOCK

The general relations of the veins and the major faults are shown in figure 20. The veins in the Wellington fault block east of the Great Northern and J faults trend about N. 70° E., whereas the main veins in the Oro fault block to the west strike nearly northeast, except in the region close to the Bullhide fault, where they assume an east-northeast direction. Many small fissures carrying ore were found east of the Great Northern-J fault zone, but only four strong veins were recognized; from north to south they are the East Iron vein, the East vein, the Orthodox vein, and the Great Northern vein. The veins are spaced about 200 feet apart on the upper levels of the Wellington workings and dip 45°–85° S. The ore varied from mixed lead-zinc ore in the northern veins to high-grade zinc ore in the southern veins, and the northern veins bottomed at shallower depths than those to the south. The veins carry ore close to the Great Northern-J fault and become unproductive 400 to 600 feet to the east.

East Iron vein.—The East Iron vein is the northernmost vein in the Wellington fault block and comes to the surface on the east side of the J fault in the quartz monzonite porphyry dike on Prospect Hill. It strikes about N. 60° E. and dips 55° SE. The vein was mined long ago and is reported to have yielded little but oxidized lead ore. According to R. M. Henderson, the general manager of the Wellington mines, the vein definitely bottomed about 200 feet above the Wellington first level and was stoped to the surface. The ore shoot extended about 220 feet to the east of the J fault and was broken by a few minor cross faults.

East vein.—The East vein is about 250 feet south of the East Iron vein and about 225 feet east of the inclined shaft on the Wellington no. 1 level. It strikes N. 70° E. and dips 65° S. on the first level but flattens to 40° and bends sharply to the south as it approaches the J fault on the second level. The ore bottoms from 15 to 30 feet below the no. 2 level and has been stoped to a point about 75 feet above the first level. The J fault sharply limits the vein on the west, and some very large masses of ore occurred at the junction. On the second level the ore shoot extended without interruption from the J fault to a small cross fault 300 feet east, beyond which the ore was of too low grade to mine. On the first level the ore shoot is broken by several nonpersistent faults, but good ore was found for 380 feet beyond the J fault. The average width of the vein is about 4½ feet, but it ranges from 2 to 12 feet. The vein carried a mixed lead-zinc ore whose average tenor was about 3 percent of lead, 20 percent of zinc, and 18 percent of iron.

Orthodox vein.—The Orthodox vein was cut by the X-10-U-8 tunnel 390 feet south of the inclined shaft and is about 250 feet south of the East vein on this level. West of the J fault the vein strikes about N. 75° E. and dips steeply to the north, but east of the fault it strikes about N. 50° E. Its dip, which is vertical or steeply north near the fault, changes to steeply south about 200 feet to the east. Coincident with the change to a southward dip, a large ore shoot occurred. The Orthodox vein is mineralized throughout most of its length, but no commercial ore was found west of the J fault, although it was explored to the Main vein, which offsets its west continuation about 35 feet to the northeast. Exploration of the offset portion of the Orthodox vein for 260 feet west of the Main vein on the Wellington no. 2 level did not reveal commercial ore.

East of the X-10-U-8 tunnel the Orthodox vein turns north into the J fault, through which it was followed with difficulty for 90 feet before it emerged and turned northeast. According to Ransome,[72]

> East of the tunnel, however, the entire drift supposed to be on the Orthodox vein is in soft, very much disturbed rock in which the vein can be followed only as a series of crushed fragments. The numerous gouge-filled slips for the most part show no regularity in arrangement of direction and appear to have little individual persistency; but better exposures would probably show the vein to be cut by north-south faults much as is the East vein. Doubtless some of these fissures continue from one vein to the other. At about 200 feet from the Extenuate tunnel the vein is displaced by a strong gouge-filled fissure with a dip to the east of only 15°. The general disturbance in the neighborhood of this fault, however, is so great as to obscure its effect on the vein and the direction and character of the displacement were not ascertained.

[72] Ransome, F. L., op. cit., p. 133.

The zone described by Ransome is near the south end of the J fault and within the influence of the northern part of the Great Northern fault, which branches and splits into many slips a short distance to the southeast. The J fault offsets the eastern side of the Orthodox vein about 75 feet to the north of its western continuation. Several smaller northerly faults offset the vein in the same direction as the J fault in the workings farther east.

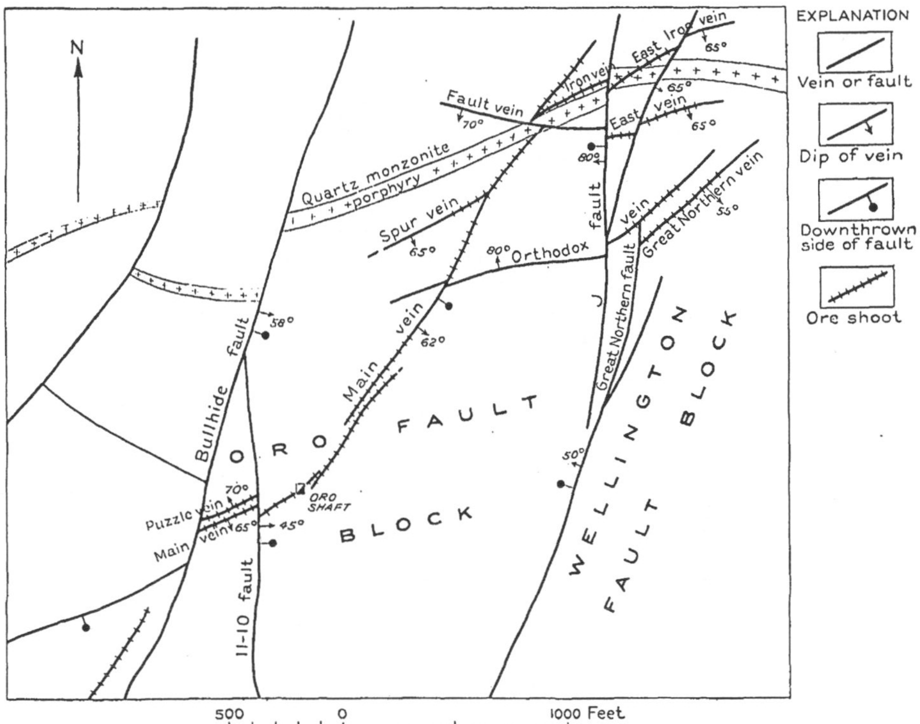


FIGURE 20.—Generalized surface map of chief veins and faults of Wellington and Oro mines.

There is a series of old stopes above the no. 1 level which starts just east of the J fault, and the ore taken from this part of the vein is reported to have carried considerable lead. The vein dips to the north throughout its length on the first level, and no commercial ore was found. The principal ore shoot on the Orthodox vein occurred 225 feet east of the J fault on the second level, where the vein dips to the south. The shoot was about 280 feet long on the second level and 320 feet long on the third level and bottoms 60 feet below. Near the western limit of the shoot some good ore was found between the first and second levels along fissures dipping gently to the south. This "flat ore" branched off into the footwall of the vein and was entirely in porphyry. Steeply dipping northerly faults limited the ore shoot at each end. The ore was almost wholly dark sphalerite and contained little lead, iron, or gangue. The productive part of the vein was about 3 feet wide and was entirely in porphyry.

Great Northern vein.—The Great Northern vein is cut by the no. 1 level 140 feet south of the Orthodox vein and about 550 feet east-southeast of the Wellington shaft. The general strike of the vein is N. 65° E., and its dip is 30°–55° S., the steeper dips occurring below the third level. It has been explored a maximum distance of 1,200 feet to the east of the Great Northern fault but has not been recognized west of the fault. As shown on the stope map (fig. 21), the ore is limited on the west by the Great Northern fault and changes into low-grade pyritic ore to the east. The length of the shoot ranges from 800 feet on the fourth level to 500 feet on the first level and is less than 200 feet at the surface. Apparently only the very top of the ore shoot has been removed by erosion. The ore bottoms abruptly about 40 feet below the fifth level, at an altitude of about 9,560 feet, but because of the gentle dip of the vein in the upper levels the shoot has a dip length of 900 feet.

The Great Northern vein is one of the most productive veins developed by the Wellington Mines Co. Its width ranged from 3 to 20 feet and averaged about 6 feet. The changes in width were not related to changes in wall rock, for though most of the vein is in porphyry, the fifth level is largely in shale, and here the vein showed no decrease in strength. At many places, notably on the fourth level, the ore widened as the Great Northern fault was approached, reaching a maximum width of 35 feet at this place. This width of ore probably is due to the mineralization of a crushed wedge of rock between the vein and a northwestern branch that splits off about 50 feet east of the fault.

The ore from the Great Northern vein was largely sphalerite and pyrite. Little lead occurred, and rarely did it exceed 2 percent of the ore as mined. Some large bunches of galena were found on the fourth level near the Great Northern fault, and for a time the average lead content of the ore increased to 2.4 percent. In general the lead content was slightly higher in the upper part of the vein than elsewhere, changing from about 0.5 percent on the fifth level to about 1.7 percent on the first level. At the bottom and east end of the shoot the zinc ore changes within a short distance into pyrite. The transition from 25 percent zinc ore into nearly pure pyrite occurred in about 20 feet at many places on the eastern edge of the shoot. This change in character was not coincident with a decrease in the width of the vein, and on the fifth level some fair-sized stopes were made in the pyrite, which was shipped to the Western Chemical Co. at Denver and used in the manufacture of sulphuric acid. The vein becomes small east of the pyritic border, and no ore was found in an exploratory drift driven 500 feet east of the ore shoot on the fifth level.

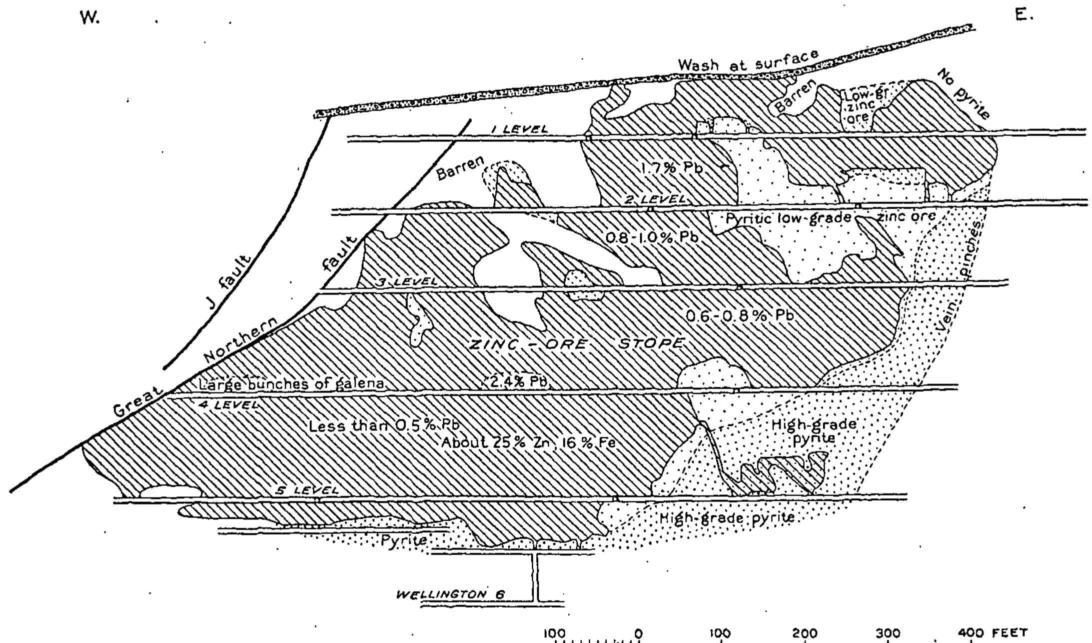


FIGURE 21.—Stope map of Great Northern vein.

VEINS IN THE ORO FAULT BLOCK

In the Oro fault block the most notable vein is the Siam vein, or Main vein, as it is now called. It strikes N. 45° E. and dips about 62° SE. It can be clearly traced from the Oro shaft to a point about 1,500 feet northeast, where it is cut by the eastward-trending Fault vein. The Iron vein, which strikes northeast and dips 65° SE., leaves the Fault vein on the north at a point about 50 feet west of the Main vein. According to Ransome,[73] it is probably a segment of the Main vein that has been displaced by the Fault vein. The Spur vein branches west from the Main vein about 400 feet southwest of the Fault vein. Near the Oro shaft the Main vein splits into two or three parts. West of the 11-10 fault the northern fracture is called the Puzzle vein and the strongest of the southern veins is called the Main vein. The Puzzle vein dips about 70° N. and trends about N. 70° E., being nearly parallel in strike to the southward-dipping fractures correlated with the Main vein.

Fault vein and Iron vein.—The Fault vein was cut by the X-10-U-8 tunnel 110 feet north of the collar of the inclined shaft. The vein strikes N. 70° E. and dips 55°–75° S. It consists chiefly of broken rock and strong seams of gouge but contains a little ore and is probably in large part premineral. The movement along the Fault vein, however, is later than the fault fissure which became the Main vein and which, as noted above, offsets it about 50 feet, the northern part or Iron vein moving west. In the Iron vein the ore bottomed about 75 feet above the X-10-U-8 level and was stoped to the surface. The ore shoot was about 3 feet wide and was entirely in porphyry. The ore was chiefly galena and cerusite close to the surface but abruptly changed into pyritic galena-sphalerite ore with depth.

Spur vein.—The Spur vein branches westward from the Main vein about halfway between the Orthodox and Fault veins. It strikes about N. 70° E. and dips 60°–65° S. It contained high-grade galena ore close to the surface, in the Prize Box tunnel, and two tapering branches of this shoot extended down to the Wellington first level, and the western branch continued to the Wellington second level. The ore below this level was bunchy and erratic in occurrence but contained more galena than the ore in the Main vein nearby. Ore from the Spur vein from the Price Box tunnel (altitude, 10,250 feet) is shown in plates 6 and 7, *A*.

Main vein.—As shown in figure 20, the Main vein extends from the J fault southwest to the Bullhide fault, a distance of nearly 3,000 feet at the surface. Its course is interrupted by several cross faults, the most notable of which are the 11–10 fault and the Fault vein. The segment northeast of the Fault vein has been described. Throughout most of its length the Main vein strikes N. 45° E. and dips about 60° SE. It is not a single mineralized fissure but a mineralized fault zone, and at several places it splits into two or more veins. The vein was not productive throughout its length, and some drifts followed barren zones as much as 1,000 feet long.

One of the best ore shoots was found a short distance east of the J fault where the Main vein is cut by the Fault vein. This shoot was roughly triangular in shape, coming to a point about 100 feet northeast of the inclined shaft between the fourth and fifth levels. A northerly fault, dipping 50° E., marked the western edge of the ore shoot; the J fault limited it on the east below the third level; and the Fault vein formed the east side of the shoot above the third level. The ore ranged from 2 to 18 feet in width and averaged 12 feet throughout the second level. It was chiefly sphalerite but contained moderate amounts of galena.

Southeastward along the vein from the inclined shaft several small ore shoots occur, but none of them extend below the Wellington fourth level until the Main ore shoot is entered, 500 feet southwest of the fifth station of the inclined shaft. (See pl. 15 and fig. 22.) This ore shoot has been stoped from the Oro eighth level nearly to the surface and was one of the largest bodies of ore in the mine. On the eighth level the shoot is only 150 feet long and is cut off on the east by northerly faults that dip steeply to the west. The intersection of the vein with the faults dips gently to the southwest and forms the bottom of the ore shoot between the eighth and seventh levels. The east end of the shoot is not marked by faults above the seventh level, and the west side of the ore shoot is not related to faults on any of the levels. In most places the limits of the shoot are marked only by a decrease in the width and tenor of the vein. On the seventh and eighth levels, however, the vein splits into several smaller veins soon after it passes into the shale at the west end of the shoot, and the branches contain little workable ore east of the 11-10 fault. Above the sixth level the shoot splits, the eastern part extending almost vertically upward to the Oro second level, whereas the western part trends upward to the west. The eastern branch probably extended to the surface, as it was apparently stoped above the Wellington second level before 1900. The western branch of the ore shoot is not known to extend more than 100 feet above the Wellington fourth level. On the fifth level the two branches of the shoot are very short, neither branch extending along the drift for more than 50 feet. Above the Wellington fourth level, however, both branches show a marked increase in their horizontal dimensions. Ore was found for nearly 700 feet in the western branch above the level and for 300 feet in the eastern branch. Both walls are monzonite porphyry above the sixth level, but between the sixth and seventh levels the limy Niobrara shale appears in the footwall in the southwestern part of the shoot. Niobrara shale forms both walls on the

[73] Ransome, F. L., op. cit., p. 132.

eighth level, except in the northeastern part of the workings, where the hanging wall is monzonite porphyry. The shale dips 15°–20° E. and underlies the monzonite porphyry, which in some places follows the bedding and in other places breaks steeply across it, rising to the west much more steeply than the bedding planes of the shale. In general the strength of the ore shoot decreased as the vein passed from porphyry into shale, but porphyry walls are no assurance that the vein contains ore.

Much of the ore above the Wellington fourth level averaged about 8 percent of lead, 15 percent of zinc, and about 0.05 ounce of gold and 5 ounces of silver to the ton. The ore from the lower levels carries decidedly less lead and more zinc. In the upper portions of this ore shoot good lead ore was in some places underlain by heavy pyritic material carrying very little lead or zinc. (See fig. 22.)

The ore shoot in shale is the first notable one southwest of the Main ore shoot. An almost barren stretch of vein about 800 feet in length separates the two ore shoots on the fifth and sixth levels. The stope length of the shale shoot is about 150 feet, and the pitch length is about 500 feet. The shale shoot bottoms on the 11-10 fault about halfway between the sixth and seventh levels and probably extends to the surface. In longitudinal section, as shown in figure 22, the shoot has a chimneylike shape and pitches about 75° SW. In the upper levels both walls are monzonite porphyry, but below the Oro third level the shoot lies in part between shale and porphyry walls and in part between shale walls. Where both walls are shale the ore is said to be narrower but of higher grade than where one or both walls are porphyry. The ore contained more lead than the average of the Main shoot and showed little change with depth.

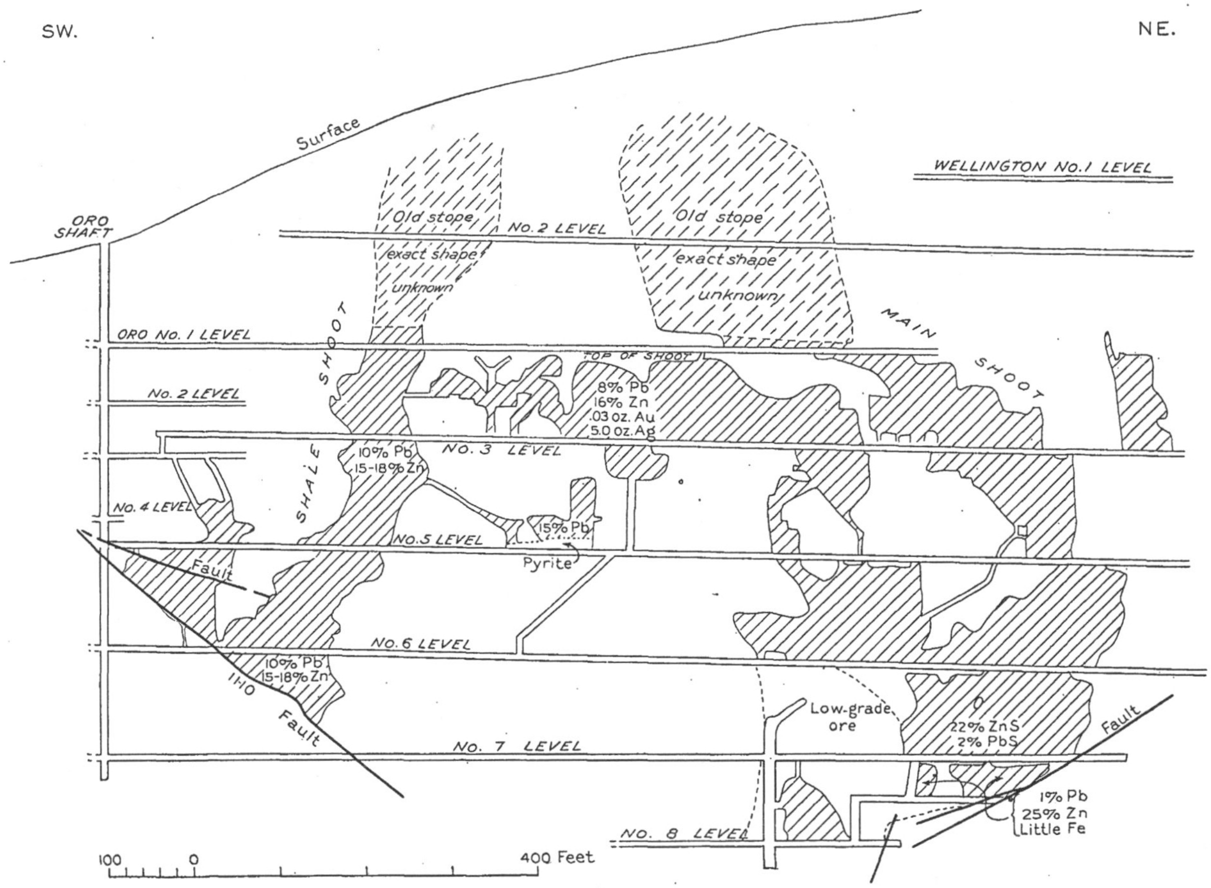


FIGURE 22.—Stope map of Main ore shoot and shale shoot on Main vein.

Several small ore bodies have been found on southward-dipping branches of the Main vein west of the shale ore shoot. The location and relation of these ore bodies is shown on the level maps in plate 15.

Puzzle vein.—In the broken ground west of the 11–10 fault the most conspicuous and easily followed vein is known as "The Puzzle." It strikes N. 65° E. near the Bullhide fault and swings to N. 85° E. a few hundred feet farther east, but unlike the veins previously described, it dips about 75° N. It is not certainly known to be a continuous fissure, and the West Puzzle ore found on the Oro third level may occur in a fissure parallel to and north of the vein in which the ore is found on the fifth level. The relations shown on plate 15 indicate that both shoots occur in the same fracture zone, but the disturbed character of the ground west of the 11–10 fault makes it difficult to correlate individual fissures.

On the eighth level several good bunches of ore were found in the faulted segments of the Puzzle vein that were being explored when the mine closed in 1929. The ore on this level was not as abundant as that on the fifth, sixth, and seventh levels, but two stopes in much broken by cross faults, extends west from the 11-10 fault for about 100 feet. The complexity of the fissuring on this level can only be suggested in maps whose scale is less than 50 feet to the inch, but the general relations are indicated on plate 15 and figure 23. The Puzzle ore shoot lies entirely between porphyry walls and is distinctly higher in lead than the ore in the Main vein east of the 11–10 fault on the same level.

The West Puzzle ore shoot was found about 325 feet west of the Oro shaft on the third level. It

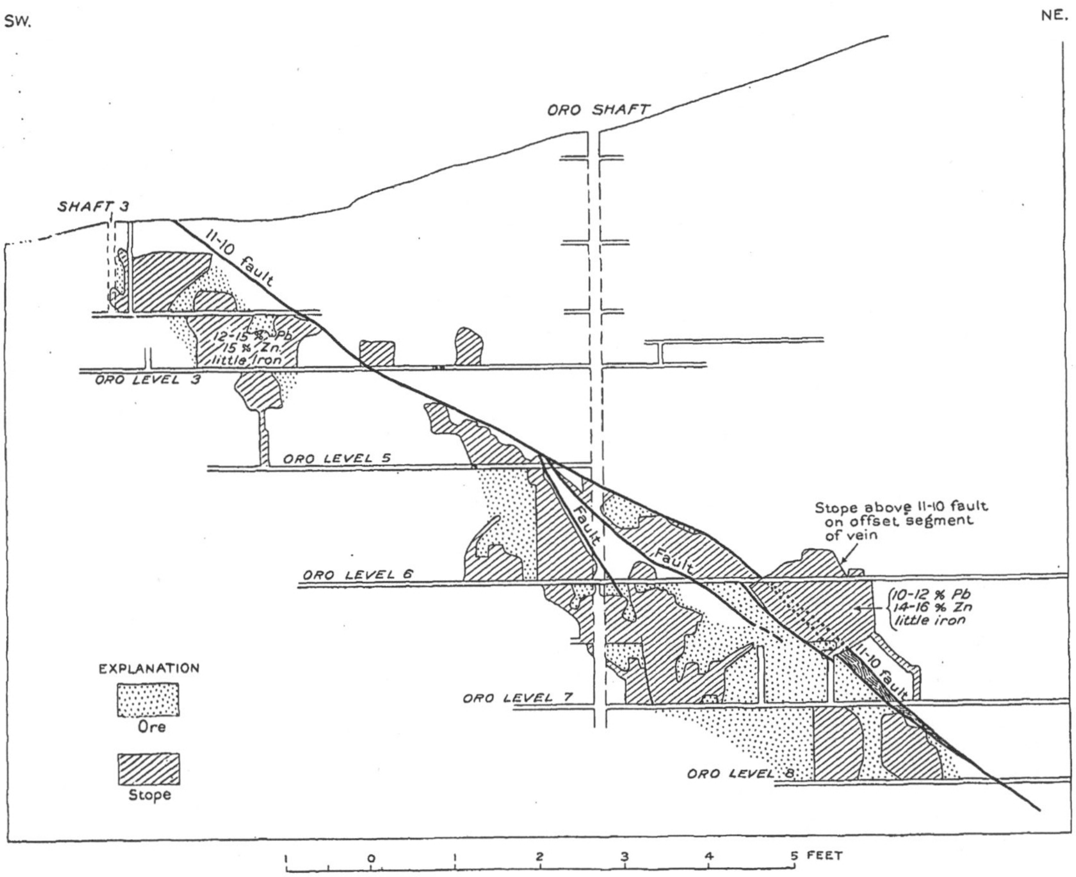


FIGURE 23.—Stope map of Puzzle vein.

good lead ore were carried up to the seventh level, as shown in figure 23. On the seventh level good ore was found from the Bullhide fault to a point about 200 feet to the east, where a small premineral fault cuts across the vein, throwing the east side about 3 feet to the north. Beyond this fault the vein is much narrower, and as it is followed through successive faults it becomes less and less productive. The ore shoot is strongest near the Bullhide fault on the seventh level but diverges from the fault as it is followed upward. On the sixth level the ore shoot begins about 80 feet east of the fault and continues to the 11-10 fault, about 260 feet farther east. On the fifth level the ore shoot, occurs in a vein that strikes N. 60° E. and dips 65° N.; the position, trend, and dip suggest that it is a continuation of the Puzzle vein opened in the lower workings. The ore has been stoped up to the 11-10 fault, about 110 feet above the level, and has been followed along the strike for about 100 feet. About 75 feet above the level, near the western edge of the ore shoot, the vein becomes vertical, and above this point it dips 70° S. The widest part of the shoot was found where several strong fissures came into the vein at acute angles. (See pl. 15.) The ore in the West Puzzle shoot lies between a shale footwall and a monzonite porphyry hanging wall. It is very similar in character to the ore found in the eastern stopes on the Puzzle vein but contains more gold.

GENERAL FEATURES OF THE ORE AND THE VEINS

The character of the primary ore has been well described by Ransome [74] as follows:

> The vein material is composed essentially of pyrite, sphalerite, and galena in various proportions with relatively little gangue. Such waste as occurs within the ore bodies consists as a rule of horses or small fragments of metallized porphyry or of pyrite containing too small a proportion of galena and sphalerite to be classed as ore. The gangue, where present, is siderite or barite. These materials, however, are nowhere abundant and are younger than the sulphides, in which they occur as veinlets or as the lining of vugs.
>
> Metasomatic replacement has played an important part in the formation of the veins, but the process * * * has been confined to fissured or crushed rock. Consequently the ores * * * lie as a rule between fairly well defined walls, which correspond closely to the original boundaries of the main fissures. Fragments of porphyry within the fissure zone, especially if of small size or traversed by many cracks, have been more or less changed to ore, partly by the filling of interstices and open spaces, partly by replacement. The ore is generally solid and firm and is accompanied by no persistent gouge along either wall. Locally gouge may be present between walls and ore, and the ore bodies in a few places are traversed by fissures filled with crushed ore or gouge. In the vicinity of faults, also, the ore is fissured and broken. * * *
>
> The prevailing texture is that of a granular aggregate of galena, sphalerite, and pyrite, the three being combined in different proportions in different places and showing much variation in coarseness of crystallization. Crystals of galena attain the largest size, some of them being 2 inches across. This, however, is exceptional.
>
> A very characteristic feature of the Wellington ore is the manner in which it is traversed by white or pale-buff veinlets of carbonate approximating siderite in composition. In some parts of the veins these veinlets, most of which are less than an inch in width and are inclined to be vuggy along their middle planes, are arranged parallel with the walls of the Main vein, giving the ore a banded appearance. In other places the carbonate veinlets branch irregularly through the sulphides in all directions [see pl. 14, *B*], and in a few places the sulphides have been brecciated and the fragments are now cemented by the sideritic carbonate. * * * The siderite is present in some form in nearly all of the ore, either as the veinlets just described or as the lining or filling of small interstices in the original porous bodies of sulphides.

The carbonate veinlets described by Ransome are common in the sulphide ore of the eighth level and are undoubtedly primary. The ore in the deepest workings does not differ appreciably in appearance from much of the ore found in the upper levels. Nevertheless, there are changes in composition that are related to depth and structure. The highest-grade lead ore was found close to the surface and usually became more zinciferous in depth. In some places high-grade lead ore changed downward into a heavy pyritic ore, which marked the bottom of that part of the ore shoot. Ores composed chiefly of sphalerite bottomed in places with no appreciable change in composition and in other places gave way to massive pyrite both vertically and laterally. Sudden changes in composition commonly mark the top, bottom, or sides of an ore shoot, but most of the ore from a given shoot is remarkably similar and is commonly characteristic of the particular shoot from which it was taken.

On the seventh and eighth levels sphalerite is distinctly younger than pyrite, and galena cuts both minerals in veinlets. (See pl. 7, *B*, *C*.) In the upper levels this order is not everywhere the same. In the Main vein west of the 11-10 fault on the third level pyrite, sphalerite, and galena seem to be contemporaneous in all the specimens examined. Ore from the shale shoot on the Wellington fourth level showed galena and sphalerite that were apparently contemporaneous, galena cut by many veinlets of dark sphalerite, and sphalerite cut by veinlets of galena. Some fine-grained pyrite accompanied the late sphalerite, but most of the pyrite was early and moderately coarse grained. Chalcopyrite occurs in minute blebs and stringers in the dark sphalerite and is most abundant in the early variety of sphalerite. In ore from the third level chalcopyrite also occurs in small grains at the edges of moderately light colored late sphalerite that does not contain the minute inclusions of chalcopyrite that characterize the early variety. Porous, nodular ore from the ground above the first level is shown in plates 6 and 7, *A*. Early galena was brecciated and recemented by dark sphalerite containing many inclusions of chalcopyrite. The sphalerite is surrounded by coarse pyrite and galena that are probably still later. Very fine grained pyrite, which may be supergene, encrusts some of the coarse-grained galena.

Replacement ore from the West Puzzle stope contained veinlets of galena, gold, and a small amount of sphalerite, pyrite, and quartz, cutting silicified limy shale in which fine-grained galena was abundantly disseminated.

The general order of deposition interpreted from the relations described above is as follows: (1) Pyrite, (2) quartz locally, (3) sphalerite (variety marmatite) and intergrown chalcopyrite, (4) sphalerite and galena, (5) sphalerite and chalcopyrite, (6) galena and pyrite, (7) galena, sphalerite, and gold, (8) quartz, (9) ankerite, siderite, calcite, and barite.

As the pyrite and sphalerite on the lower levels were deposited earlier than galena, and as galena is contemporaneous with much of the sphalerite on the upper levels, the sphalerite in the lower part of an ore shoot was probably formed at an earlier stage in the epoch of mineralization than the sphalerite in the upper parts of the same shoot. In other words, the deposition of the sulphides extended over an appreciable period of time, and ore formed in large amounts at the bottom of an ore shoot sooner than it did at the top.

[74] Ransome, F. L., op. cit., pp. 133-134.

OXIDATION OF THE ORE

It was impossible to study the upper parts of the veins in 1928, and the following paragraph on the oxidation of the ores is quoted from Ransome:[75]

Even along the outcrops of the veins most of the shafts and tunnels show some galena in the claylike product resulting from thorough oxidation, and the change to essentially sulphide ore generally takes place at depths of less than 300 feet. The depth of the oxidized zone, however, varies, being greatest in general near the crest of the ridge in which the ore bodies occur and least along the lower slopes. On the main levels of the Wellington mine the ore as a rule shows no oxidation, although in a few places there has been a slight development of smithsonite in interstices of sphaleritic ore. Owing to the inaccessibility of the old upper workings there is little opportunity at present for studying the transition from partly oxidized ore to sulphide ore. The normal sequence, however, from the surface down, appears to be (1) a soft, heavy, yellowish claylike ore consisting largely of earthy cerusite and containing residual nodules of galena; (2) a lead-silver ore in which the galena is only in part oxidized, while the pyrite has been for the most part changed to limonite and the sphalerite altered to smithsonite and limonite, with removal of zinc in solution, and finally (3) a lead-silver-zinc ore in which galena predominates and in which the early stages of oxidation are indicated by the formation of a little spongy smithsonite, or "dry bone", as the miners call it, at the expense of the zinc blende.

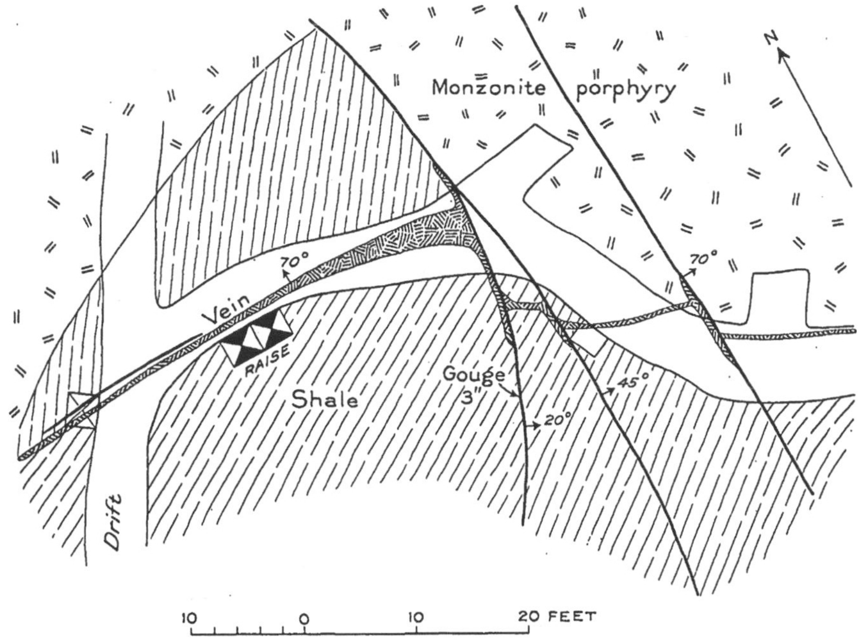


FIGURE 24.—Ore enlargement at premineral fault, level 7, Oro mine. Note stringers of ore following faults.

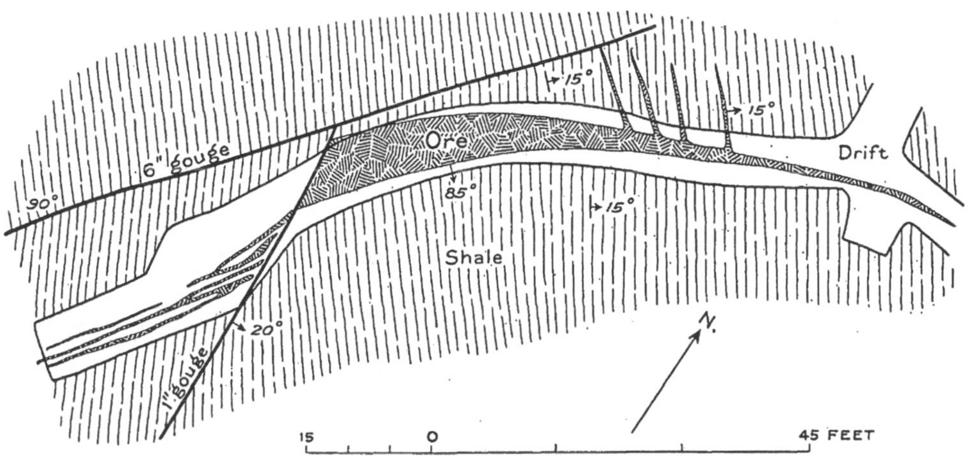


FIGURE 25.—Enlargement of ore as vein approaches premineral fault, level 3, Oro mine.

OCCURRENCE OF ORE

Evidence has been given to show that the major faults originated before the period of mineralization. In figures 24 to 28 the influence of preexisting faults on ore deposition is illustrated. In some places premineral cross faults acted as guides to the mineralizing

[75] Ransome, F. L., op. cit., p. 134.

solutions and determined the limits of an ore shoot; in other places the cross fault opened up the vein on one side and closed it on the other and thus caused a

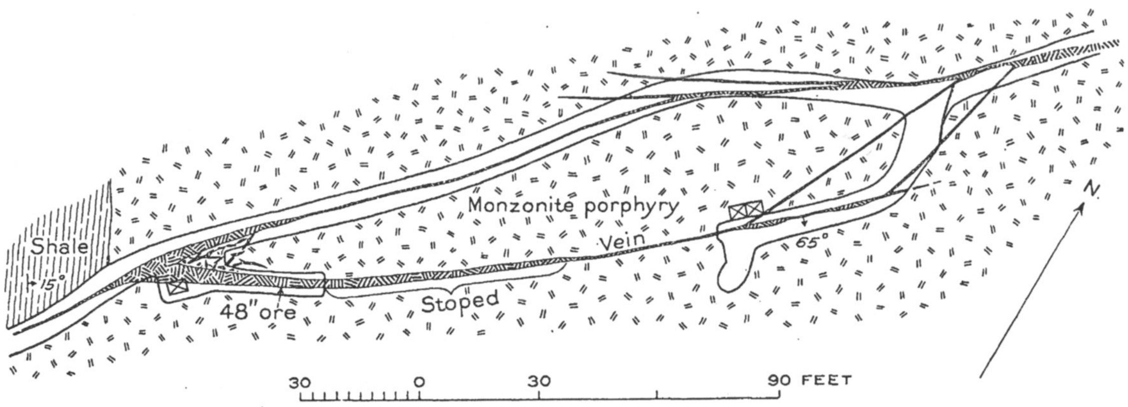


FIGURE 26.—Local enlargement of ore at intersection of branch vein, level 6, Oro mine.

local enlargement and "pinch" in the ore. Some of the ore shoots seem to be related to the variations in the dip of the vein. The slipping of the irregular

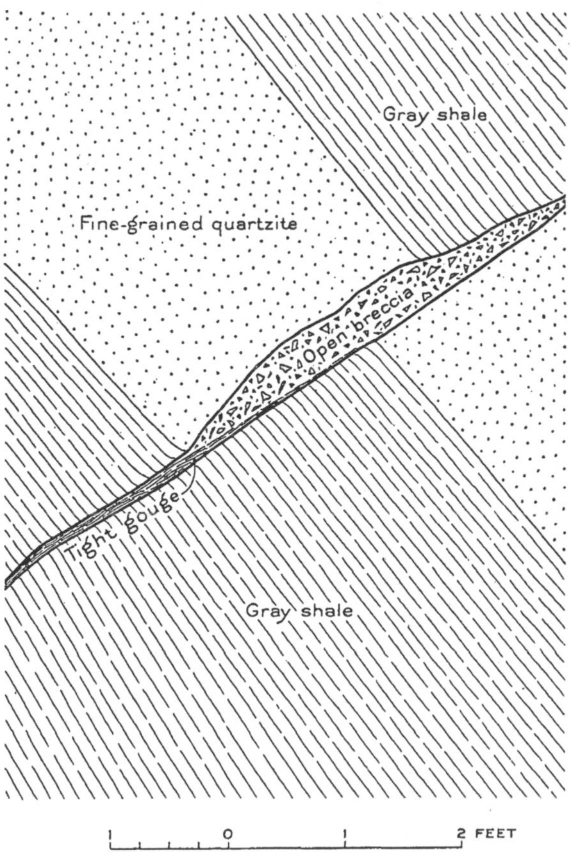


FIGURE 27.—Fracturing of interbedded shale and quartzite, level, 6 Wellington mine.

surfaces of a fault will produce open spaces as well as tight contacts between the walls, and a normal fault will tend to develop openings wherever the dip steepens, whereas a reverse fault becomes open where the dip flattens. So far as known, all the veins of the Wellington mine are in normal faults, and most of the ore shoots occur where the vein becomes steeper or where it changes its course. Thus the decrease in ore at the top of the Great Northern vein coincides with a marked flattening of the vein, and the steepening of the Main vein in the upper levels is marked by an increase in the width and length of the Main ore shoot. The physical character of the wall rock influences the permeability of the material in a fault, and ore chan-

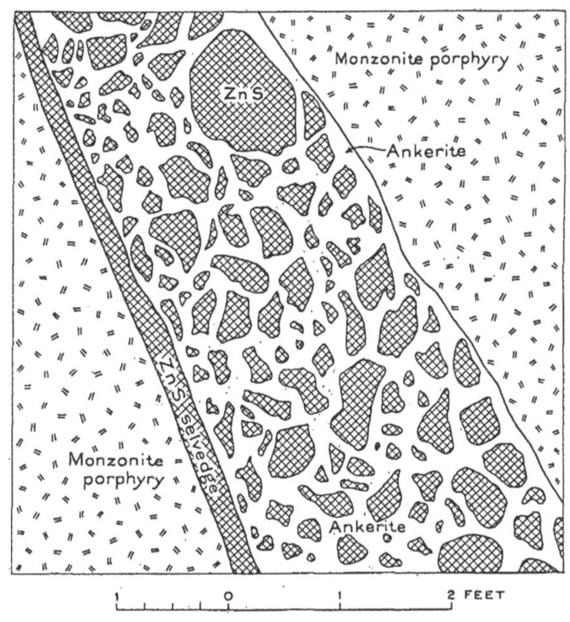


FIGURE 28.—Brecciated marmatite cemented by ankerite, level 7, Oro mine.

nels are stronger and more persistent in porphyry or jasper than in unsilicified shale. (See fig. 27.)

The presence of two ore shoots that have not suffered appreciable erosion—the western branch of the Main ore shoot and the Great Northern ore shoot—gives an unusual opportunity to study the character of the primary ore and to trace the relation of the ore to the structure of the region. The zinciferous character of the Great Northern vein and its relation to the Great Northern fault have already been pointed out. As pyrite and sphalerite are early minerals, it is probable that this vein was filled before the shoots on the Main vein or those in the veins farther north, which were richer in lead. If the Great Northern fault acted as a guide for the metallizing solutions and they filled the Great Northern vein before the other veins, the solutions must have followed a northerly course along the master fault. Thus the open fissures communicating with the footwall of the fault were filled as the northward-moving solutions reached them; in a general way the southern fractures were filled and healed before those to the north. Intermineralization movement along the Great Northern-J fault probably opened ore channels communicating with the Bullhide fault and with the Main vein. The higher proportion of lead in the ore shoots near the Bullhide fault suggests that the solutions did not have access to them until late in the period of mineralization.

GUIDES TO ORE AND FUTURE OF THE DISTRICT

Only a small part of the Breckenridge district has been studied by the writer. Most of the known ore has been exhausted in this special area, but the relation of ore to structure seems established, and there are some places where the writer believes that more work should be done. The occurrence of ore in the Wellington mine, summarized on pages 50–59, suggests that shoots of ore are most likely to be found in northeastward-trending veins close to strong northward-trending faults, which acted as trunk channels for the metallizing solutions. Thus the ground close to the Bullhide fault north of the Puzzle vein may contain workable bodies of ore on some of the fissures that are known to branch from the Main vein farther east. The Wellington Main vein, as noted on page 49, is offset by the Bullhide fault, and, as shown on plate 2, the western continuation of the vein, mantled by wash and completely unexplored, is probably directly beneath the wagon road to the Wellington mine. This unexplored portion of the vein is about 800 feet long. Good galena ore was picked up by the dredge where it crossed a vein parallel to the Bullhide fault and about 150 feet farther west. This vein should intersect the western segment of the Wellington Main vein about 100 feet west of the Bullhide fault. Although the wall rocks of the vein here are not as competent to form open fissures as porphyry or quartzite, the distance to quartzite on the hanging wall is probably not more than 50 feet. This is one of the most promising unexplored localities in the special area.

In Gibson Hill the blanket deposits have been found chiefly in the upper part of the Dakota formation, but the occurrence of replacement deposits in the upper part of the Maroon formation and the presence of calcareous beds in the Morrison formation, which might carry ore, suggest the possibility of deeper ore shoots beneath the blanket ores of the Dakota. Most of these deposits have been small, however, and it is doubtful if the cost of exploration for such deep deposits could be justified. In the faulted area east of Gibson Hill, where the Benton shale crops out, it is possible that core drilling into the upper part of the Dakota formation might discover some ore shoots that could be profitably mined.

South of French Gulch there is a possibility of finding ore in cross fissures close to the southward continuation of the Great Northern-J fault zone, but the mineralization on this side of the gulch was apparently less intense than on the northern side. The fissures in the thick porphyry sill that makes up most of Nigger Hill are probably weak and poorly mineralized in the underlying shale, but there is a strong probability that gold enrichment occurs in some of the veins at the shale-porphyry contact, as it did in the Dunkin vein. It is possible that the veins are stronger and carry ore in the Dakota quartzite, which lies at different altitudes near Nigger Hill, as shown in plates 2 and 5. South of Nigger Hill, in the mines between Dry Gulch and Illinois Gulch, ore has been found only in the rocks above the Morrison formation. If this relation is not fortuitous, the only area of much promise that has not been explored is under the Benton and Niobrara formations west of the Golddust vein. This unexplored ground is chiefly in the bottom of Illinois Gulch and undoubtedly contains much water, so that exploration may be too expensive unless it can be done by geophysical means.

In conclusion, the amount of known ore left in the special area is a very small part of that originally present, and the discovery of additional ore will probably depend on the correct interpretation of the structural geology. Geophysical work in areas that are structurally favorable for occurrence of ore, supplemented by core drilling, will probably be the most economical method of ore hunting in most places, although the western continuation of the Wellington Main vein can probably be cheaply prospected by means of test pits.

PRODUCTION TABLES

The available information on the production of most of the mines described in this report is summarized in the following tables. The production since 1906 is believed to be accurately shown, but as the figures for the preceding years are incomplete no totals are given. The writer expresses his appreciation of the fact that with the exception of the Royal Tiger Mining Co. none of the owners or lessees have withheld permission to publish the production figures for their properties.

Metals produced from crude ore shipped to smelters from Country Boy mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Zinc (pounds; gross)
1889	(?)	23.77	477		
1902 [a]	1,500			28,553	
1906	1,640				1,223,623
1907	727				727,000
1909	2,876				2,588,400
1911 [b]	2	.37	20	1,976	
1912 [b]	101	14.37	352		73,478
1913	276				250,884
1914	267				244,127
1915	[c] 436	2.26	72	106	166,268
1916	[d] 458				320,576

No production in 1887-88, 1901, 1903-5, 1908, 1910, 1917-28; no record for 1890-1900.

[a] Probably Juniata.
[b] May include production from the Juniata.
[c] *Includes 396 tons of crude ore that was treated in concentrating mills. About* 132 tons of zinc concentrates were produced, containing 77,173 pounds of zinc. The 40 tons of smelting ore contained 36,848 pounds of zinc. No gold, silver, or lead recovered.
[d] Estimated tonnage and content of concentrates produced from 939 tons of crude ore.

Metals produced from crude ore shipped to smelters from Detroit-Hicks mine

[See also table for milling ore]

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Copper (pounds; wet assay)	Zinc (pounds; gross)
Dry gold and silver ore:						
1922	68	38.80	1,498	5,287		
1923	141	106.30	1,237	2,514		
1924	136	33.40	1,351	415		
1925	188	96.70	2,758	7,764		
1926	52	8.40	429	1,683	105	
1927	([a])	17.00	816			
Lead ore:						
1923	1,632	252.30	49,644	521,139	2,228	
1924	1,044	180.15	32,822	359,316	201	
1925	21	6.30	514	2,930		
1927	16	9.41	1,083	7,457		
Lead-zinc ore:						
1923	102	13.80	1,448	11,984		51,951
1924	118	18.29	1,641	10,397		54,465
1926	[b] 311	176.79	2,566	13,103	2,225	78,341

[a] Less than ½ ton.
[b] Content of crude milling ore, only estimated figures available for concentrates produced.

Ore from Detroit-Hicks mine treated at mills, and gross content of concentrates produced from it

[See also table for smelting ore]

	Ore to mills (short tons)	Concentrates produced (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Copper (pounds; wet assay)	Zinc (pounds; gross)
1927	200		[a] 12.71	[a] 973			
		14	68.00	560	2,116		
1928 [b]	1,835		[a] 1.47	[a] 152			
		93	67.90	3,000	15,615	96	18,937

[a] Bullion.
[b] Includes Extension mine.

Metals produced from crude ore shipped to smelters from Extension mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)
1912	4	1.32	68
1913	12	5.87	158
1914	101	116.69	134
1915	(?)	3.92	1
1916 [a]	(?)	5.26	2
1926	13	[b] 30.30	[c] 1

No production in 1901-11, 1917-25, 1927; for 1928 see Detroit-Hicks.

[a] From milling ore.
[b] Includes 3.83 ounces gold bullion (amalgam).
[c] Bullion (amalgam).

Metals produced from crude ore shipped to smelters from Dunkin mine

[See also table for milling ore]

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Copper (pounds; wet assay)
1890	(?)	15.00	339	29,855	
1891	(?)	129.00	3,492	402,362	
1901	230	101.60	3,335		
1902	125	63.00	544	117,647	
1903	150	75.00	1,500	105,882	
1904	(?)	1.11	748		
1906	80	59.99	1,200	56,471	
1907	250	150.01	3,250	176,470	
1908	675	445.00	7,425	457,227	
1909	110	102.56	1,273	72,013	
1910	205	73.24	10,130	129,519	
1911	94	94.01	1,034	59,220	
1912	688	568.55	9,603	435,491	1,840
1913	259	165.83	2,497	145,342	49
1914 [a]	100	357.72	812	51,581	51
1915 [b]	127	534.65	1,249	58,062	608
1916	125	1,414.74	1,706	39,989	144
1917	186	252.57	658	98,491	320
1918	73	62.70	611	31,777	146
1920	20	15.60	112	3,272	
1926	8	3.80	78	3,610	
1928	14	21.10	101	3,270	

No production in 1905, 1919, 1921-25, 1927; no records for 1892-1900.

[a] Includes 3 tons of dry ore containing 170.44 ounces of gold and 136 ounces of silver.
[b] Includes 23 tons of dry ore containing 469.22 ounces of gold and 288 ounces of silver.

Gold and silver produced from ore from Dunkin mine treated at mills

[See also table for smelting ore]

	Crude metal (ounces)	Gold		Silver	
		Fine ounces	Fineness	Fine ounces	Fineness
1910	44.56	31.31	0.7026	11	0.2468
1913	2,344.79	1,383.02	.5898	901	.3842
1914	2,562.39	1,701.63	.6641	834	.3254
1915	2,931.85	1,992.26	.6795	864	.2948
1916	1,908.52	1,218.81	.6386	556	.2912
1917	23.63	15.66	.6625	8	.3279
1924	85.98	51.39	.5977	24	.278

Metals produced from crude ore shipped to smelters from Germania group [a]

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Copper (pounds; wet assay)
1889	(?)	6.82	1,929	19,374	------
1890	(?)	100.00	------	198,924	------
1901	150	675.00	7,500	------	------
1902	87	64.33	4,968	------	------
1903	240	320.00	49,800	------	1,714
1904	94	40.15	4,404	------	------
1905	133	78.37	8,079	------	------
1906	164	38.31	4,482	28,586	------
1907	11	1.11	835	5,705	------
1908	20	8.57	1,741	------	------
1909	75	1.60	531	4,211	------
1912	5	.64	146	------	------
1913 [b]	21	2.62	584	2,445	------
1915	73	2.40	2,978	2,380	------
1916	307	26.43	9,213	12,755	------
1920	156	6.50	2,306	------	------
1928	3	.20	121	297	------

No production in 1887-88, 1910-11, 1914, 1917-19, 1921-27; no records for 1891-1900.

[a] Figures for some years may include production from Morning Star.
[b] Includes 13 tons of dry ore containing 221 ounces of silver.

Metals produced from crude ore shipped to smelters by Little Mountain Milling & Mining Co. [a]

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)
1887	(?)	15.75	6,011	31,479
1888	(?)	19.35	9,393	----------

[a] Probably belongs to Germania group.

Metals produced from crude ore shipped to smelters from Juniata mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)
1889	(?)	206.68	3,370	120,507
1890	(?)	500.00	7,540	1,662,430
1892	(?)	1,162.14	2,694	185,393
1914	11	3.43	117	8,635

No production in 1901, 1903-10, 1913, 1915-28; no records for 1891, 1893-1900; for 1902, 1911-12, see Country Boy.

Metals produced from crude ore shipped to smelter from Ouray mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)
1890	(?)	334.50	12,611	633,713
1891	(?)	566.41	58,505	610,728
1892	(?)	1,342.33	118,022	2,043,515
1915	5	4.08	128	768

No production in 1901-14, 1918-28; no records for 1893-1900; according to the report of the Director of the Mint, the report of production for 1889 was confidential; production for 1916-17 may be included in report for Golddust and Puzzle.

Metals produced from crude ore shipped to smelter from Pacific mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Zinc (pounds; gross)
1905	300	24.19	331	7,509	--------
1906	175	24.19	330	7,513	--------
1914	8	1.88	86	5,649	--------
1916	180	110.48	2,728	105,963	--------
1928	9	4.40	119	1,221	452

No production in 1901-4, 1907-13, 1917-27.

Metals produced from crude ore shipped to smelters from Puzzle mine and dump

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Copper (pounds; wet assay)	Zinc (pounds; gross)
1887	(?)	4.79	777	--------	------	--------
1888	(?)	53.95	379	18,973	------	--------
Lead ore:						
1915	21	12.12	266	5,529	------	--------
1916	116	67.03	936	29,772	242	--------
1917	111	70.64	1,142	28,651	418	--------
1925	13	4.10	119	2,677	------	--------
Lead-zinc ore: 1916	356	214.40	4,623	124,750	2,731	207,313

According to the report of the Director of the Mint, the report of production for 1889 was confidential.

Ore from Puzzle mine and dump treated at mills and gross content of concentrates produced from it

	Ore to concentrating mills (short tons)	Concentrates produced (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)
1902	400	(?)	50.00	1,400	11,765
1903	500	(?)	58.06	1,400	11,800
1916	350	70	119.44	1,102	66,843

Metals produced from crude ore shipped to smelters from Golddust mine [a]

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Copper (pounds; wet assay)	Zinc (pounds; gross)
1902	1	3.53	2	--------	------	------
1904	[b] 1,461	1,022.00	23,376	687,616	------	------
1905	[b] 395	194.04	5,589	27,909	------	------
1906	[b] 348	68.65	2,921	160,331	------	------
1907	[b] 795	214.01	6,665	137,825	------	------
1908	236	159.49	3,245	122,520	------	------
1909	85	41.61	1,023	41,085	------	------
1911	17	5.97	267	16,404	321	------
1914	65	48.00	1,016	16,601	125	------
1915	174	55.03	2,702	164,626	------	------
1916	199	60.38	3,044	206,171	------	------
1917	20	18.66	302	10,000	------	------
1928	7	.80	45	2,397	31	613

No production in 1901, 1910, 1912-13, 1918-27; production for 1903 may be included in table for Puzzle mine.

[a] For some years production for Puzzle mine is included.
[b] Probably includes crude ore shipped to smelters and concentrates produced from milling ore.

Metals produced from crude ore shipped to smelters from Washington mine

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)
1890	(?)	250.00	4,713	390,759
1909	34	8.31	723	47,238
1911	9	5.64	187	4,392
1912	18	6.06	341	11,499
1913	22	5.58	432	19,452
1915	29	17.50	305	7,480
1916	46	27.53	484	15,827
1917	36	17.04	467	17,564

Gold and silver produced from ore of Washington mine treated at mills

	Ore to mills (short tons)	Concentrates produced (short tons)	Gold (fine ounces)	Silver (fine ounces)
1904	1,500	(?)	264.00	7,500
1916	(?)	--------	[a] 6.88	[a] 7
1917	(?)	--------	[a] 5.95	[a] 4

[a] Bullion.

Metals produced from crude ore shipped to smelters from mines of Wellington group

	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Copper (pounds; wet assay)	Zinc (pounds; gross)
1887 (Oro claim)	(?)	102.60	2,874			
1888 (Oro claim)	(?)	211.40	3,518	325,382		
1889 (Oro claim)	(?)	103.54	7,158	47,275		
1890 (Oro claim)	(?)	480.00	20,359	2,557,586		
1891	(?)	45.23	1,045			
1889 (Prize Box Vein)	(?)	118.84	796	53,301		
Lead-zinc sulphide smelting ore:						
1904	4,200	210.00	84,000	4,941,176		2,016,000
1905	583	17.46	3,001	158,344		291,325
1909	1,950		2,120	745,883	3,480	928,000
Zinc sulphide smelting ore:						
1910	1,342					1,017,200
1911	150					108,783
1912	1,260					819,000
1916	2,025					1,832,810
1917	5,873					5,006,578
1918	1,898					1,717,584
1919	209					177,232
1922	750					846,006
Lead smelting ore:						
1908	197	4.83	247	228,395		
1915	35	4.78	854	52,386		
1918	37	2.00	500	18,744		
1920	31	7.08	706	33,021		
1922	766	84.50	7,131	287,226		
1923	364	23.30	3,942	117,630	42	
1924	162	11.40	1,611	50,367		
1925	251	10.40	3,360	154,351		
1926	48	1.70	449	17,579		
1927	118	15.49	1,367	64,139		
1928	170	20.91	2,124	123,137		
Dry silver smelting ore:						
1916	218	11.23	1,089			
1920	612	24.48	2,448			

Lead-zinc ore from mines of Wellington group treated at Wellington mills

[Short tons]

1905	2,770	1917	41,900
1906	862	1918	39,117
1907	5,200	1919	11,103
1908	2,811	1920	30,401
1909	10,500	1922	2,114
1910	23,496	1923	42,552
1911	30,930	1924	21,586
1912	33,322	1925	23,743
1913	19,013	1926	31,740
1914	17,403	1927	20,179
1915	38,846	1928	19,810
1916	39,230		

Metals produced from ore from mines of Wellington group treated at Wellington mills

	Concentrates (short tons)	Gold (fine ounces)	Silver (fine ounces)	Lead (pounds; wet assay)	Copper (pounds; wet assay)	Zinc (pounds; gross)
Lead concentrates:						
1910	3,452	156.58	38,990	2,999,237	1,845	(?)
1911	4,718	50.25	56,591	4,035,711		(?)
1912	3,222	86.67	50,073	3,053,776	4,815	(?)
1913	2,617	143.94	30,491	2,547,240		(?)
1914	1,307	117.22	21,518	1,158,306	2,613	(?)
1915	1,433	86.84	21,919	1,417,142		(?)
1916	298	43.33	9,671	352,537	70	(?)
1918	114	15.90	3,832	133,662		(?)
1919	122	7.20	2,694	68,011		(?)
1920	243	37.78	4,742	168,858		(?)
1922	170	7.58	2,040	117,920		(?)
1923	4,282	775.50	47,117	3,461,772	82	(?)
1924	2,168	353.50	21,303	1,870,110		(?)
1925	2,913	333.30	30,531	2,734,619		(?)
1926	2,832	418.70	29,281	2,662,886		(?)
1927	843	126.24	16,682	972,832		(?)
1928	1,190	316.76	20,856	1,453,346		534,820
Iron concentrates:						
1916	3,388	152.60	14,319	10,823	318	
1917	8,061	341.34	38,098	7,277	953	
1918	2,353	120.20	14,654	28,745		
1920	297	14.11	1,188			
1923	448	38.40	1,588	7,362	104	
Zinc concentrates:						
1905	(?)	69.03	14,188	778,974		1,325,021
1906	(?)	16.06	4,249	251,538		416,826
1907	(?)	117.02	23,400	1,127,200		1,996,800
1908	790			451,988		1,138,852
1910[a]	6,630					4,325,500
1911	9,266					7,726,403
1912	11,804					9,862,747
1913	8,678					7,458,723
1914	5,798					5,356,157
1915	10,262					9,428,807
1916	15,444	1.47	4,545	19,857		14,047,189
1917	20,715					19,347,039
1918	17,201					17,304,206
1919	4,782					4,881,634
1920	10,394					10,322,902
1922	418					401,000
1923	9,454					9,061,002
1924	3,666					3,792,338
1925	1,848	49.10	4,573	89,456	17,897	1,790,175
1926	4,715					4,666,173
1927	5,852					6,160,015
1928	4,114	90.50	9,661	91,439	41,650	4,412,091
Lead-zinc concentrates:						
1909	5,250	883.96	55,988	3,161,122		2,492,000
1925	1,585	30.00	4,000	504,734	99,380	1,557,897

[a] Includes 2,072 tons of zinc middlings containing 1,545,500 pounds of zinc.

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